ELEMENTARY PHYSIOLOGY AND ANATOMY

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BY

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PREFACE

THIS book is intended to give an idea of the structure of the body, and of the changes which are constantly taking place in it during life, to those who have no previous knowledge of the subject.

It has accordingly been written in as elementary a fashion, and with the use of as few technical terms, as possible, so as to be intelligible to the general reader.

The subject is such a vast one that an outline sketch is all that can be presented in a volume of the dimensions of the present one, but it is hoped that this sketch will be sufficiently clear to give a fair idea of the subject to the student of *Physiology* before he proceeds to more detailed study with the aid of larger text-books.

Such a bird's-eye view of the subject as is here shown ought to prove of advantage to the junior student, who is often plunged into a mass of detail, and gets so involved in this that he loses sight of the main outstanding features of the subject.

At the same time, it is hoped that the book may attract a larger circle of readers and may remove some of that deplorable ignorance which is so often met with, even among fairly well educated people, as to the general structure of their own bodies and the actions which take place within them during life.

Physiology is a subject with which a living acquaintance can only be made by employing experimental methods, and hence

it is very desirable that the student should as far as possible perform for himself the experiments described in the text. It is further to be hoped that doing so will train him to habits of observation, and awaken his interest so that he will be able in the end to see for himself things to which his attention is not specially directed by others.

In conclusion, I desire to thank my friend Mr. D. P. Rockwood for his kindness in revising the proof-sheets and preparing the index. Most of the illustrations have been selected, by kind permission of the Editors, from Quain's "Anatomy," and of Prof. Schäfer, from his "Essentials of Histology."

B. MOORE.

UNIVERSITY COLLEGE, LONDON,
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PREFACE TO THE SECOND EDITION

IN the present edition, the title of the book has been changed from "Elementary Physiology" to "Elementary Physiology and Anatomy," because the amount of space devoted to anatomical description forms such a considerable share of the book, that it really is an introduction in outline to the study of both the structure of the body and the functions of its different organs. The only changes which have been made in the text consist in the correction of verbal slips.

B. MOORE.

UNIVERSITY OF LIVERPOOL,
1904.

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ELEMENTARY PHYSIOLOGY

CHAPTER I.

INTRODUCTION.

PHYSIOLOGY is the study of the changes which go on in living matter. Throughout the entire life of any living creature various changes are constantly taking place, and it is by means of the impressions conveyed to our senses by these changes, which awaken other changes in us, that we are made aware of the life of the creature.

The forms of life which we can recognize in the world around us are countless in their variety, but all these forms have this in common that a store of energy is taken in from the outer world in various ways and used by the living creature to carry out the different acts or changes which constitute its life.

In a broad sense of the word, physiology includes the study of the life of plants as well as that of animals, but plant life is the special province of the botanist. The physiology of the lower forms of animal life is also usually left to the care of the zoologist. We shall hence devote the greater part of the space at our disposal to giving an outline of the physiology of man and of those animals which are closely allied to man in their structure.

It will be well, however, before doing so to very briefly describe the simplest type of animal life with which we are acquainted, in order to obtain some general idea of how this simple form of life is structurally related to the more complex animals which we have subsequently to consider.

The simplest form of animal life with which we are acquainted is a minute speck of material which is only visible through a microscope. Small as it is, it is however a complete organic whole, capable of showing all the essential characteristics of life, and of producing, at what corresponds to the end of its existence as an individual unit, other similar organisms which repeat again an existence that is a *fac-simile* of its own. Examples of organisms of such a simple type are to be found in the *amœba* of pond water, and also in the *leucocytes*, or *white blood corpuscles*, which carry on a separate but dependent existence during our life in our blood. These leucocytes exist in the blood of all the higher animals. They live in the blood so long as it circulates in the body, but soon after the blood is shed, or after the animal dies, the leucocytes perish.

When examined by the aid of a microscope, each of these simple little organisms is seen to consist of a mass of very irregular outline. The material of which it is composed is more or less granular in appearance, and the granules, although usually minute, vary in size. At one part of the tiny organism the material is seen to be somewhat denser and less transparent in structure. This denser portion is usually rounded or globular in shape, and is also more granular than the remainder; it is known as the *nucleus*, and when the organism is in a resting position occupies a central place in the mass.

If this little mass of living material be carefully and patiently observed through the microscope, it will be found that its shape does not remain constant; there is a slow change going on in its outline, and in a short time its appearance may be quite different from that which it had when first observed. The rate at which the alteration in shape goes on varies with certain circumstances, such as the temperature of the fluid in which the organism is immersed and the presence of food particles in its immediate neighbourhood; but usually the rate is not so sudden as to be very obvious to the eye. It is only when the organism is watched for a time that the change in shape becomes evident, and a clear idea of how the change

takes place is best obtained by sketching the outline at intervals of a minute, or by watching one of the jagged processes in the irregular outline. It is then seen that the movement which brings about the change of shape, or it may be a change in position of the creature as a whole, is a flowing one. At an indefinite point, a minute process apparently spontaneously grows out from the main body; this is at first clear in its interior, later it grows in size and becomes granular inside from an accession of granular material from the main body. More than one such process—or, as it might be termed, feeler—is usually to be seen at any time projecting from the main mass.

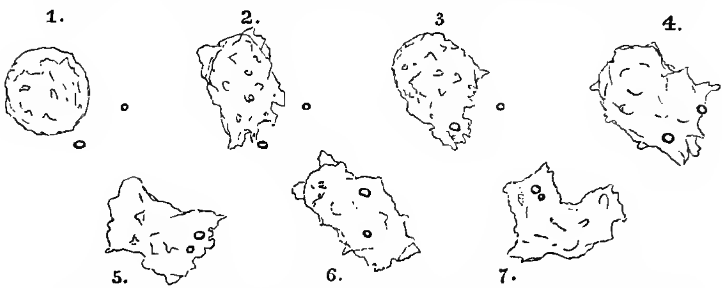


FIG. 1.—Changes of form of a white corpuscle of newt's blood, sketched at intervals of a few minutes, showing the inception of two small granules and the changes of position these underwent within the corpuscle. (E. A. S., Quain's "Anatomy.")

The size to which a process can grow depends upon circumstances; occasionally after it has reached a certain size it is again withdrawn into the main mass, as if a determination had been made at some headquarters that nothing was to be gained by further motion in that direction. At other times a process goes on increasing in size until finally the whole of the mass has flowed into it, and the animal has completely changed its position. In many cases such a continued growth of a process is due to the existence of a food particle in that direction. In such a case the mass of the organism flows round the particle, envelops it in its mass for a time, and afterwards rejects any unserviceable debris that may be left by flowing in the same slow fashion away from it.

The minute organism seems to become aware, in some

way, of the presence of a food particle even before it has touched it, possibly from minute traces of dissolved substances surrounding the particle of food which become stronger as it is approached. Various chemical substances determine movements of the organism towards them, or away from them, or prevent movement altogether and cause the creature to assume a spherical shape. Electric shocks passed through the fluid have a similar effect, the processes are all drawn in, and the creature becomes a rounded mass. After a time, if the disturbing influence be removed, the processes are gradually formed again, and the flowing movement recommences. If stronger chemical reagents are used, or if the fluid in which the animal lives is heated above a certain temperature, death is the result. The existence of one of these tiny organisms as an individual may terminate in one of two ways; it may die in some way, or it may resolve itself into two smaller organisms, which afterwards increase in size and repeat a life history like that of the single organism from which they originated. When the organism is well supplied with food it takes up more than is sufficient to supply energy for the changes in shape above described. The food is changed within the mass, and is in part chemically altered and built up into the organism, so that the bulk goes on increasing until a maximum size is reached. Soon after this the denser portion, known as the nucleus, begins to constrict at its middle, becomes hour-glass shaped, and finally divides into two; next the general mass also constricts a portion forming round each of the new nuclei, and finally there are two smaller masses formed, each with a new nucleus. Each of these new masses is thus started into life as a new individual, and so the cycle goes on repeating itself.

When the materials of which the bodies of animals are made up are examined under the microscope, it is found that they consist of aggregations of minute units which are related in their nature to the simple organism which has been described above. These microscopic units are spoken of as *cells*. Each cell typically consists of a minute mass of semi-fluid material called *protoplasm*. At one part this protoplasm is different from the remainder; it is here denser and more complex in its

structure, and is known as the *nucleus*. The nucleus seems to be the most highly vitalized portion of the mass, and any important changes in the life of the cell, such as its division into two new cells, commence first in the nucleus. *Granules* are often visible within the cell protoplasm; these are not part of the protoplasm in the sense that they are not living, but are usually composed of material which has been made by the protoplasm from the food on which it has acted. This material is afterwards used for carrying on various operations which make up the life of the cell.

Thus each living cell in the animal's body resembles its fellows, in that it takes in certain substances in the form of food, and changes these substances chemically into other substances, or, as it is called, *assimilates* them. These new substances serve various ends. For example, some supply a store of energy to the cell to carry on its own life; others are turned out again to form nutriment to other different cells in the body; others, again, stream off in solution to act on the food of the animal, and render it capable of *absorption* by another class of cells.

The cells which go to make up the bulk of an animal vary enormously in their appearance. Only a very small percentage are capable of freely moving about, and taking in food in the same fashion as the simple *unicellular* organism which has been described above as a type. By far the greater number are fixed in shape and position; these must have their food brought to them in solution, for they cannot absorb solid particles; they must be bathed in a nutrient fluid which is carried to them in some manner, and this nutrient fluid must be prepared in some fashion from the solid food which the animal, of which they form a part, eats from time to time.

It is hence easy to see that in animals consisting of large colonies of cells there must be a division of labour; one class of cells performing one class of work, while another class carries on another. This purpose is best attained by an arrangement by which those cells which carry on the same kind of labour are situated at the same place, and such is the arrangement which is found in the animal body. The cells are not situated

indiscriminately, but in aggregations, each consisting of a very large number of similar cells carrying out a similar purpose. To these aggregations of cells different names are given for purposes of description, such as *tissue*, *organ*, *gland*, and *body*.

"Tissue" is the most general of these terms, and is applied to any assemblage of cells designed for a common purpose. Thus there is a tissue found generally all over the body, the purpose of which is to bind such aggregations of cells as we have been describing into bundles and masses, and to form sheaths and coverings for them; this is known as *connective* tissue. Again, the muscles of the body by which the movements of the animal are brought about are made up of cells which are collectively spoken of as muscular tissue.

The term "organ" is more restricted in its application, and is usually applied when the purpose served by the mass of cells is more specific in its character. Thus the heart is an organ, the purpose of which is to send the blood streaming round the body, carrying nutriment to the cells of which the other tissues and organs are composed. Since it is chiefly composed of muscular tissue, it is further called a muscular organ. An organ may thus be composed of several different tissues, just as a rock may be made up of different minerals. For example, the heart contains connective tissue, and adipose or fatty tissue, as well as muscular tissue. Also a tissue may go to form a part of very diverse organs; thus muscular tissue is found in the skeletal muscles, in the heart, in the walls of blood-vessels, and in the coats of the alimentary canal.

A *gland* consists mainly of aggregations of cells the purpose of which is to take up certain materials from the blood, and from these to make new materials, which are either *returned to the blood* to be of service to the animal at some other part, or to be excreted from the body as useless and injurious by some other gland; or *are sent into a collecting vessel called the duct of the gland, dissolved in a watery fluid which is known as the secretion of the gland.*

These gland secretions serve many purposes in the body. Some are *lubricants*, such as the secretion of the lachrymal

gland of the eye, which serves to keep the eyeball moist and float off any irritant particles which may reach the sensitive surface of the eyeball. The *chief* function of the saliva secreted by the salivary glands is similarly to coat the food as it is swallowed with a slippery envelope, and render its passage to the stomach an easy one. Other secretions contain substances dissolved in them which act on the food eaten by the animal, dissolve it, and render it capable of absorption by those cells which line the passage called the alimentary canal by which the food passes through the body. These secretions will be considered more fully in treating of digestion.

In other cases the secretion of the gland contains only substances which are either of no service, or directly injurious to the body, and the purpose of the secretion is to secure the removal of these from the circulating blood-stream, and so away from the body; in such a case, the process, though really identical in nature with that of secretion, is spoken of as *excretion.* The best example is that of the kidneys. Here substances which exist ready formed in the blood, and the accumulation of which in the blood would lead to the poisoning of the cells and to the death of the animal, are kept down to a normal level by being continuously removed by the secreting action of the cells of the kidney. In the case of the liver the secretion (*the bile*) has a mixed character. Some of the substances held in solution are useless to the body, and are finally carried away from the body, mixed with the unused and indigestible part of the animal's foods. Other substances secreted in the bile are useful in the process of digestion, and are absorbed again by the cells lining the alimentary canal.

Certain glands in the body do not possess ducts, and have no obvious secretion. Before their true nature was known, some of these ductless glands were spoken of as *bodies.* It is not yet known how these ductless glands act, but it is certain that they exert a powerful influence over the welfare of the animal, and in the case of some of them their removal is followed by the death of the animal. It is supposed that they act like glands in removing certain materials from the blood, and in elaborating from these materials others which are

returned to the blood-stream again, and serve useful and in some cases indispensable purposes in the preservation of the health of the animal. A similar kind of work is done by certain of the other glands which possess ducts. Thus it is certain that the formation of bile is not the only nor even the main work of the liver. This organ acts as a storehouse for a certain class of food, accumulating in its cells a reserve of material when the supply in the blood which comes to it is too liberal, and doling this reserve out when the supply slackens and the other cells of the body require this kind of nutriment. In addition, the liver has a modifying action on other classes of food-stuffs, but this subject will be more fully considered later.

It must not be supposed that in each of these aggregations of cells that we have been considering, there is to be found only one kind of cell. It is only meant that one type of cell preponderates in them. These cells, to do their work, must be supplied with blood, and this blood must be carried to them by blood-vessels, and away from them by other blood-vessels. The walls of these blood-vessels contain various kinds of cells specially adapted to form the walls of vessels. There is an inner lining of flat cells to give a smooth lining to the wall, and outside this, again, muscle cells encircling the vessel, which by their state of contraction or relaxation allow less or more blood to pass to the preponderating cells.[1] Again, the blood itself contains cells of different kinds. Further, the whole mass of cells must be supported and bound together by some of that connective tissue mentioned above. It is hence to be understood that in every tissue and organ of the body there is a considerable number of different kinds of cell to be found, but that the nature of these cells corresponds to the kind of work to be performed by that tissue; some being fundamentally concerned with the work in hand, while others are necessary accessories.

Harking back again to our simple type of a unicellular

[1] The blood does not flow into these cells, but flows past close to them. The manner in which the cells are nourished by the materials carried by the blood will be shown later.

organism, and comparing it with the cells which build up the body of one of the higher animals, we see that there is something essentially the same in the two cases. In the case of the simple organism, one cell carries out all the operations of existence. It takes in food; it assimilates this food and forms materials to replenish the waste of the cell; it rejects what cannot be assimilated; it moves about in the fluid in which it lives, and finally it continues its kind by dividing and producing new individuals. Similarly, a living cell forming an integral part of a higher animal carries on to a certain extent an independent existence. It takes up the food which is prepared for it and carried to it in solution; it assimilates this food and maintains its living condition by its aid, and it is capable of undergoing cell division and increasing the number of cells resembling itself. *Only* the existence of this second kind of cell is dependent on the life of the animal of which it forms a part; for on the death of the animal its supply of food stops, its means of existence are at an end, and in a *variable* but always short period of time it inevitably dies.[1]

In return for the nourishment which each cell receives from the general stock of circulating food, it performs certain services which benefit the general community of cells forming the body of which it is a minute portion.

Thus the most simple type of animal life differs from the most complex only in this—that in the latter there is minute division of labour, while in the former there is none. Accompanying this division of labour, there is naturally that adaptation of structure which is necessary to suit the instrument to its work.

The unicellular organism might be compared to an individual savage inhabiting an uncivilized region, and a component cell of a higher animal to a citizen of a civilized nation; in which case the civilized nation might further be taken to represent the mass of cells which together make up the body. The savage is able, after a fashion, to supply all his wants for himself, and carry on a certain low-grade existence without

[1] The death of the animal as a whole (general death) is hence not synchronous with that of the tissues (local death).

calling in the aid of others. The civilized man usually does one type of work only, which is useful to the community at large, and in return for this mutually receives the service of his fellows by whom he is virtually fed and clothed and supplied with comforts in proportion to the value of the work which he does. In a civilized country it is further found that work can be best and most expeditiously done when a large number combine to do it in the same place, and even certain industries are confined to certain towns and districts to the exclusion of other places and other industries. Similarly in the body, one kind of work is done in one part, and a different kind in another. Again, the centres of industries in a nation must be kept in communication with one another, and supplies of raw material and of manufactured articles must be carried from one to another. Similarly, in the body it is necessary to have a means of communication and a vehicle of transport between one part and another, and this is achieved by a stream of circulating fluid, the blood, which carries supplies to the various parts and takes away anything which it is necessary to remove. Finally, in a civilized community it is essential that there should be a governing intelligence, and a rapid mode of intercommunication between this government and the various parts. Likewise, in the body it is necessary that there should be a controlling centre or centres which can be rapidly made aware of any change in the condition of any part. This is the office of the *nervous system*, consisting of a central part, the brain and spinal cord, which by an immense network of communicating channels, the *nerves*, is placed in minute acquaintance with the state of affairs throughout the body, and to a certain extent in a position to control any changes.

Between the simplest type of living creature and the most complex type there are an infinite number of intermediate stages, so that it is possible to see how the more complex species are related to the simpler. The same thing is clearly illustrated in the development of an individual animal of one of the higher types. Every animal, no matter how complicated its final structure, commences life as a single cell of microscopic dimensions. This primitive cell, or ovum, is formed from the

body of the female parent, and after being fertilized by being penetrated by a portion of a cell (*spermatozoon*) from the body of a male parent, commences to subdivide, the nucleus first dividing, as in the case of the simple unicellular organism, and afterwards the cell protoplasm. The two cells so formed again subdivide, so giving rise to four cells, and this process is repeated a great number of times until there is instead of one cell a spherical mass of many cells. The cells become so arranged that there are larger cells at one hemisphere than at the other, and by the growth of one set of cells over the other there are gradually formed an upper and under layer. Later there is developed between these two layers a middle layer, and from these three primitive layers the various organs take origin—the alimentary canal, digestive glands, and respiratory system from the inner, the bony skeleton and muscular system from the middle, and the skin and nervous system from the outer. As the three layers are formed the spherical mass elongates, and along one side a groove is formed by a dipping in of the surface; this groove deepens and finally meets and closes at the top so as to form a canal. Around this canal the spinal cord develops, and it is in this manner that the centre nervous system comes to be developed from the external primitive layer.

To give even a complete outline of the manner in which development goes on to the final production of the perfect animal would take much more space than is occupied by this entire volume; the above is merely intended to indicate roughly how the operation of development of any animal commences from a single cell. During the process of development the growing embryo receives nutriment from the parent, so that it can grow and increase in bulk. This takes place by means of a vascular network called the placenta, in which blood-vessels from the parent ramify alongside blood-vessels from the embryo. The nutrient material passes from the parent by a process of diffusion into the blood of the embryo, and the products of excretion of the embryo pass in the opposite direction. In this manner the life of the embryonic animal is maintained until its development is sufficiently advanced for it to carry on

an independent existence, and soon after this stage is reached it becomes separated from the parent.

Every animal, no matter how complicated its structure, then, may be looked upon as an aggregation of physiological units called cells. These cells, though formed on a common pattern and produced originally from a single cell, differ from one another in detail of structure, in shape and in size, and carry on different functions in the body. The work of all these cells is designed towards one end, the welfare of the whole body, and hence the animal though made up of an immense number of living units may still be regarded as a single organic whole, and as possessing a life, as a whole, on which the lives of the component units depend.

CHAPTER II.

THE SKELETON AND ITS ARTICULATIONS.[1]

THE framework on which the body is built is called the skeleton. The skeleton consists in all of about two hundred bones, variously joined together so as to afford protection and support for the soft parts, to give stability to the shape of the body, and to render possible all those complicated movements which go on during life. The bones are fitted together at the joints, or *articulations*; those surfaces which come into contact at the joints being known as the *articular* surfaces. At some of the articulations a great freedom of movement is permitted, in others the amount of movement is but slight, and in others, again, the opposed surfaces are firmly interlocked, and no movement is possible.

The bones are living structures provided with a supply of blood for their nutriment and containing living cells. Between the organic matter of which the cells are composed, and other organic matter directly derived from the cells, there is deposited a large amount of inorganic material, chiefly consisting of the insoluble phosphate of calcium (tri-calcic phosphate). This inorganic matter is separated from the blood during growth by the cells which are engaged in forming the bone. It forms about two-thirds of the weight of the dried bone, and is that factor in the materials constituting the bone which gives hardness and strength to the structure.

[1] The student should follow this description with the aid of a set of dried bones; or, if these are not at his command, should attempt to gain access to a museum where he can study the skeleton and see the bones for himself.

A bone is not the same in its structure at all parts; strength combined with lightness is obtained by a compact firm structure, called *compact bone*, being formed all over the outside, inclosing a space which, in the case of some bones, such as the ribs and ends of the long bones of the limbs, is filled with a honey-combed, lighter structure (*cancellous bone*), and in the case of other bones, such as the shafts of the limb bones, is completely hollow, and filled only with a soft fatty tissue, the *marrow* of bone. The purpose is similar to that which causes the engineer

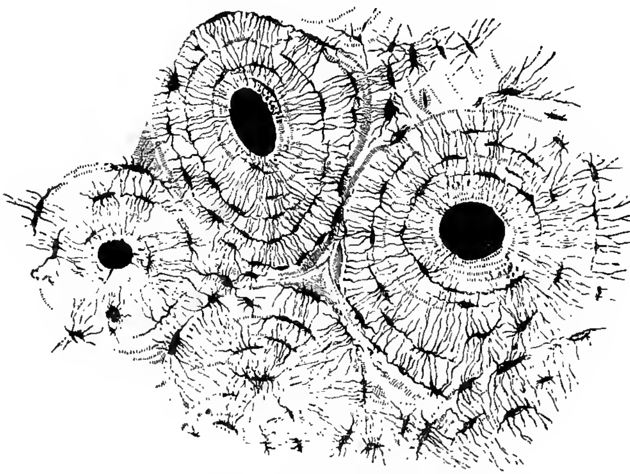


FIG. 2.—Transverse section of compact tissue (of humerus). (Sharpey.) (Magnified about 150 diameters.)

Three of the Haversian canals are seen, with their concentric rings, or lamellæ; also the lacunæ, with the canaliculi extending from them across the direction of the lamellæ.

to employ hollow pillars and girders when he designs obtaining the greatest strength with the least weight of material.

At the ends or surfaces of the bones, where they join or *articulate* together, there is found a layer of tissue known as *cartilage*, or gristle. This tissue is closely allied in nature and mode of origin to bone itself, being indeed the kind of tissue in which the forms of growing bones are first laid down, and which is afterwards transformed into bone. In the layer of

cartilage at the articular surfaces no deposition of calcium salts takes place, and no after metamorphosis into bone; this layer retains throughout life that structure which the whole bone initially had, and serves an important function in preserving the bones and the whole body from injury by any sudden jerks or jars. Cartilage is the *buffer* tissue of the body, and prevents a sudden knock at any part from being transmitted through the body. Cartilage is extensible and compressible in the same sense as a material like indiarubber;

a
b
c
d
e

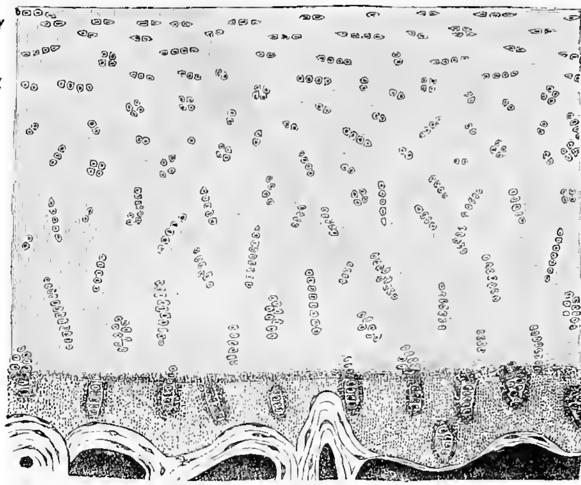


FIG. 3.—Vertical section of articular cartilage covering the lower end of the tibia, human. (Magnified about 30 diameters.) (E. A. S., Quain's "Anatomy.")

a, cells and cell-groups flattened conformably with the surface; *b*, cell-groups irregularly arranged; *c*, cell-groups disposed perpendicularly to the surface; *d*, layer of calcified cartilage; *e*, bone.

that is to say, it can easily be forced out of shape by pressure or traction in any direction, and after the deforming force is removed returns at once to its original shape. Hence it is used throughout the body to give elasticity to the movements and to prevent injury by jarring. For this reason there is a pad of it between each of the separate bones which go to form the backbone, or *vertebral column*, and also on the end of each of the limb bones. For a similar reason the ribs end in

cartilage, so as to give a flexible junction between these and the breast bone, or *sternum*, in front, and so diminish the fragility of the bony structures which protect the upper cavity of the trunk, known as the chest, or *thorax*. The surfaces of the articular cartilages in those joints where there is considerable freedom of motion, such as those of the limbs, are exceedingly smooth, so that another office of these cartilages is to prevent friction of bearings at the joints. In this work the

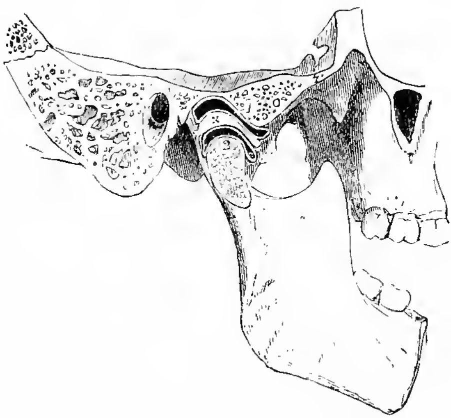


FIG. 4.—Sagittal section of the temporo-maxillary articulation of the right side. (Allen Thomson.) $\frac{1}{3}$

1, is placed close to the articular eminence, and points to the superior synovial cavity of the joint; 2, is placed close to the articular surface of the condyle of the lower jaw, and points to the inferior synovial cavity of the joint; ×, is placed on the thicker posterior portion of the interarticular disc.

smoothness of the cartilaginous surfaces is assisted by a fluid which is secreted at the joint, and is called *synovial fluid.* This synovial fluid is kept in position by the capsule of the joint. The capsule consists of a covering of dense tissue formed of strong fibres (fibrous tissue), which completely surrounds the joint, forming a closed cavity, within which the synovial fluid is secreted. Besides forming in this manner a kind of gear-case for the joint, the capsule is immensely strong, and contributes materially to the strength of the structure and to keeping the bones in position (*i.e.* from getting

out of joint). In this it is assisted at important joints by stronger fibrous bands, occurring either as local thickenings of its wall, or quite distinct from it; these structures are known as *ligaments.*

In some important joints, such as the knee joint and that of the lower jaw with the skull, the junction of the two articular surfaces is made more perfectly fitting by the interposition of a thin disc of cartilage between the two opposed surfaces, so that there is a kind of double joint, each opposed surface moving over an opposite surface of the interarticular disc. The interarticular disc is attached round its margin to the capsule of the joint, and in this way two cavities are formed, which may either be completely (jaw) or incompletely separated (knee).

The foregoing figures show the minute structure of bone (Fig. 2) and of articular cartilage (Fig. 3) as these are seen when thin sections of these tissues are prepared and examined with the microscope. A section through the articulation of the lower jaw is reproduced as an example of the structure of a joint (Fig. 4).

The Vertebral Column.

The central structure in the framework of the body is the backbone, or vertebral column, which lies in the mid line down the back. It may be looked upon as a central axis of the skeleton to which the other parts are attached. It supports the skull upon its upper end, the ribs are attached to it laterally, and at its lower end it itself is supported between the hip-bones, through which the weight of the body is transmitted to the legs.

The structure of the vertebral column is shown in the accompanying figures. It consists of a series of bones, called *vertebræ*, usually twenty-six in number in the adult, which are articulated together by intervertebral discs of cartilage in such a way that, although there is very little movement between any consecutive two, yet the column, as a whole, is flexible, and

admits of a considerable amount of bending, both from before, backward, and from side to side (see Fig. 7).

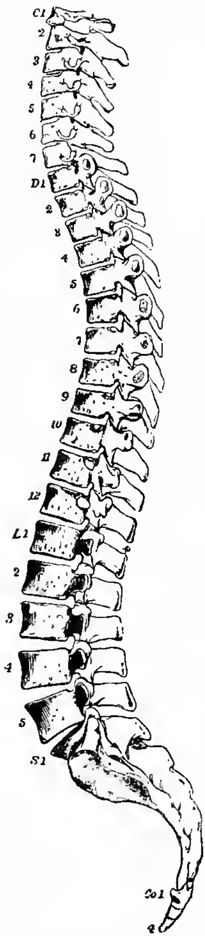


Fig. 5. — The vertebral column, viewed from the left side.

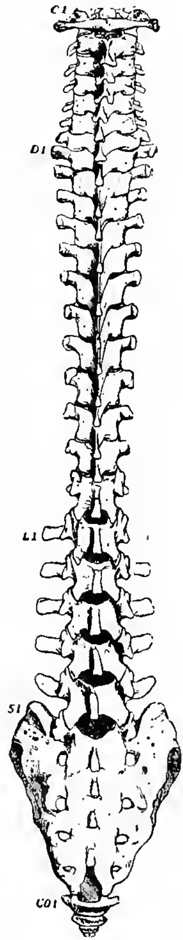


Fig. 6.—The vertebral column, viewed from behind.

C1, first cervical vertebra; D1, first dorsal vertebra; L1, first lumbar vertebra; S1, first sacral vertebra; Co1, first coccygeal vertebra. (Furneaux's "Physiology.")

With the exception of the two upper and two lower members of the series, which will be considered later, the

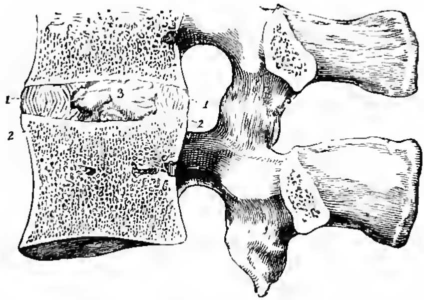


FIG. 7.—Section through two lumbar vertebræ showing the arrangement of the intervertebral disc. (R. Quain.) $\frac{2}{3}$

1, 2, the fibrous laminæ; 3, the central soft substance; the capsule of the joint between the articular processes is also shown.

vertebræ bear a close resemblance, or *homology*, to one another, and hence a description of one typical vertebra will suffice for all.

The front portion of each vertebra is a short flat cylinder, or disc, called the *body*, a little smaller in its middle than at the top or bottom. From the posterior part of the body the *neural arch* arises by two short stout processes of bone called the *pedicles.* These unite at the back in a broad flat plate called the *lamina*, which projects backwards as the *spinous process*, that part of the vertebra which can be felt through the skin at the back. A ring of bone is formed in this way surrounding a cavity which is known as the *spinal foramen.* It is evident that when the vertebræ are joined together as in the body, these cavities will form a long canal surrounded and protected by bone; this canal is called the *spinal canal*, and lodges the *spinal cord*, a delicate nerve structure which in this manner is preserved from any chance of injury. The pedicles are narrower than the body, so that there is a roughly semicircular notch at each side above and below each pedicle. When the vertebræ are in position in the body, it is obvious that there will thus be at each side between each two vertebræ

a round opening, half of which is contributed by each vertebra; these openings are called the *intervertebral foramina*, and serve to transmit the spinal nerves, a pair of which come off the spinal cord at each vertebra, as well as the blood-vessels, carrying blood to and from the spinal cord and its accessories.

From the junction of pedicles and lamina, two processes, called the transverse processes, arise, as shown in the figure.

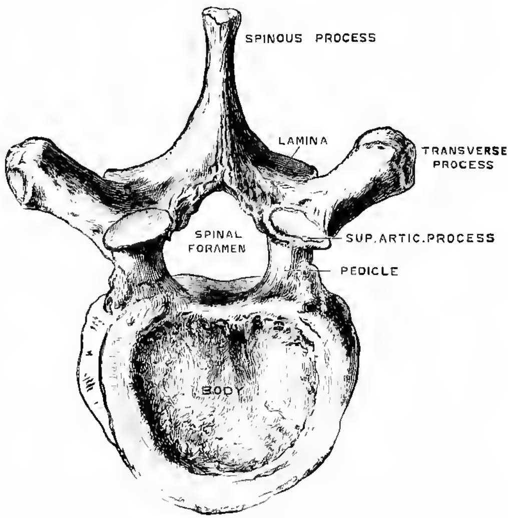


FIG. 8.—Tenth dorsal vertebra, from above. (Drawn by D. Gunn for Quain's "Anatomy.")

In the case of those vertebræ to which ribs are attached (dorsal vertebræ), each of these transverse processes bears a small articular facet, to which a similar facet on the corresponding rib is applied. On the bodies of these same dorsal vertebræ above and below on each side there is a half facet, which in each case unites with its neighbour on the nearest vertebra to make a whole facet, for articulation with the head of the rib. So that each rib has two points of attachment, one on the bodies of the vertebræ, and one on the transverse process of a vertebra.

The laminæ of the vertebræ imbricate or overlap each other, so that each vertebra has four other articular surfaces besides those on the body. This arrangement gives greater stability to the column, and is a safeguard against dislocation.

The vertebræ are further bound together by strong bands of ligament passing from one to another, especially between the spinous processes and between the laminæ. The processes of the vertebræ serve for the attachment of certain of the back muscles, which straighten the vertebral column, and for some of the muscles of the back of the neck, which tilt the head backwards on the neck.

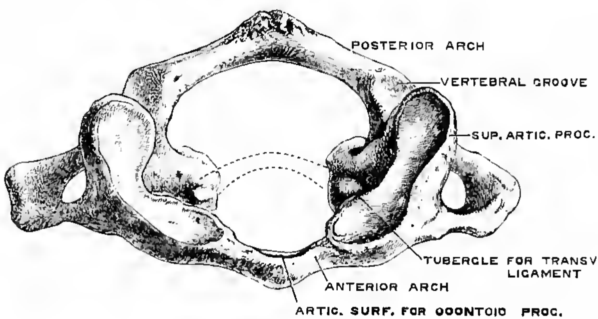


FIG. 9.—Atlas, from above. (Drawn by D. Gunn for Quain's "Anatomy.") The position of the transverse ligament is indicated by dotted lines.

The seven vertebræ at the upper end of the column are known as the *cervical* vertebræ; these form the bones of the neck. They are much more slenderly built and lighter than the lower members of the column, and are capable of moving on one another to a much greater extent, so as to allow movements of the neck. The two upper members of the cervical series are much modified in shape, in order to permit movements of the head on the vertebral column.

The first vertebra which articulates with the occipital bone of the skull is called the *atlas*, and the second vertebra, called the *axis*, articulates above with the atlas, and below with the third cervical vertebra.

The shape of these two bones, and the manner in which

they are articulated together, is shown in the accompanying drawings.

The atlas is a ring of bone, the body having disappeared, and where the body would be if present the *odontoid process*

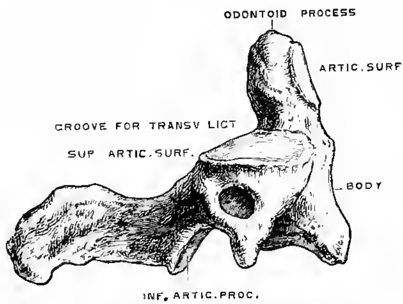


FIG. 10.—Axis, from the right side. (Drawn by D. Gunn for Quain's "Anatomy.")

of the axis projects through, round which, as on a pivot, the atlas carrying the head can turn. The strong *transverse ligament* passing behind the odontoid process completes the socket.

On the upper surface of the atlas are two articular facets

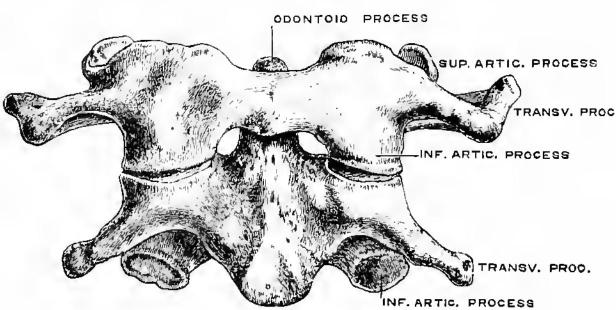


FIG. 11.—Atlas and axis, from before. (Drawn by D. Gunn for Quain's "Anatomy.")

of the form shown in the drawing (Fig. 9). These are slightly concave on their surface, and receive two similarly shaped but convex-surfaced facets placed on the occipital bone of the skull (see Fig. 13), and called the *occipital condyles.* It

is by a rocking movement of the condyles on these articular facets of the atlas that nodding of the head up and down is effected.

The varied movements of the head on the neck are mixtures of these two movements simultaneously—namely, of an up-and-down movement brought about by the rocking of the occipital condyles on the atlas, and of a rotation movement of the atlas on the axis around the odontoid process. Changes in position of the head are further assisted by movements of the cervical vertebræ, *i.e.* by bending of the neck. If the head be turned round sharply to one side, and the neck be felt on the other side, a hard mass will be felt passing from behind the ear down to the breast-bone and collar-bone on the front of the chest. This is the mass of the sterno-mastoid muscle. When the muscle of one side is contracted, and not the opposite one, the head is rotated towards the side on which the muscle lies, and depressed on that side. When both sterno-mastoids are contracted the head is depressed in front. The head is elevated by the muscles of the back of the neck acting in opposition to the muscle (sterno-mastoid) just referred to, which has been cited because it lies superficially and can easily be felt. Besides these there are other muscles which combine in producing the movements of the head. When a movement takes place, nerve impulses are sent to these various muscles along the nerves belonging to them, and a nicely adjusted amount of stimulus is given to each muscle, so as to cause just the proper amount of contraction in each in order to produce the desired degree of motion when combined with the action of the other muscles involved.

Beneath the seven cervical vertebræ come the twelve *dorsal* or *thoracic* vertebræ. These are more strongly built than the cervical, as is fitting, since they have to support a much greater load. The cervical vertebræ carry only the weight of the head; but the dorsal have the ribs attached along their sides, and have communicated to them by these the weight of the upper part of the trunk (*i.e.* the thorax) and of the upper limbs. The dorsal vertebræ may be distinguished by the facets for the ribs on their bodies and transverse processes.

The next five vertebræ are the *lumbar* (or loin) vertebræ. These are very massive in their structure, because they have to support the whole weight of the part of the body above them, and transmit it to the hip-bones. They have no ribs attached to them, and the soft parts (abdominal viscera) in the part of the trunk opposite to them are only protected by the strong sheets of muscle passing from the upper brim of the pelvis to the lower ribs.

The lowest of the lumbar vertebræ is seated on a strong bone called the *sacrum*, shaped like a curved wedge (see Figs. 5 and 6), and formed by the fusion together of a number of imperfect vertebræ. The vertebræ which make up the sacrum are usually five in number, and early in life exist as distinct bones, but later become completely fused together into one bone. By two large articular surfaces (*auricular* surfaces), one on each side, the sacrum articulates with the two hip-bones, and lying between these forms a portion of the pelvis (see Fig. 19). Strong bands and sheets of ligament pass from the sacrum to the hip-bones, and a great part of the weight is borne by these ligaments; so that the vertebral column and its load are in part borne by the articulation with the hip-bones, and in part are borne hammock-fashion by the ligaments passing from hip-bones to sacrum. The *coccyx* is attached to the lower end of the sacrum; it consists of from three to five (usually four) rudimentary vertebræ, which are commonly fused together into one bone (see Figs. 5 and 6).

It will be seen from the above description that the vertebral column is a strong and somewhat flexible pillar of bones, which upholds the weight of the part of the body lying above the hips, and affords an attachment to the ribs; besides this, it furnishes a long cavity in which the spinal cord lies. At the upper end this spinal cord enlarges into the brain, which is lodged in the large cavity of the cranium, occupying the greater part of the volume of the skull.

The Skull.

The skull may, for purposes of description, be considered in two parts—viz. the cranium, or brain-case, and the face.

The cranium occupies the upper and back part of the skull, and is formed by eight bones; the face forms the front and lower part, and is made up of fourteen bones, making twenty-two bones in the skull in all. The position and names of the various skull-bones are shown in the accompanying figures.

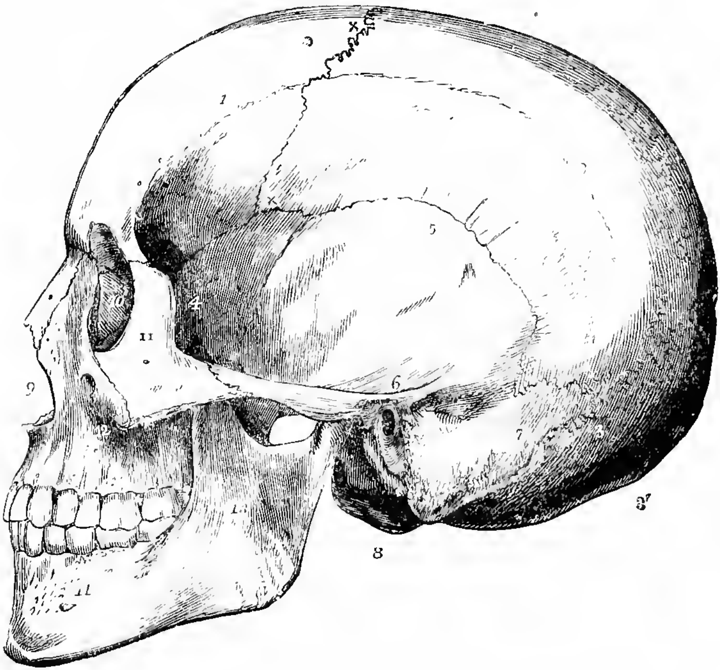


FIG. 12.—Lateral view of the skull. (Allen Thomson.) $\frac{1}{2}$

1, frontal bone; 2, parietal bone at the upper temporal line; × ×, coronal suture; 3, on the occipital bone; 3′, external occipital protuberance; 4, sphenoid bone; 5, squamous part of temporal; 6, the same at the root of the zygoma, immediately over the external auditory meatus; 7, mastoid portion of temporal, at the front of which is the mastoid process; 8, left condyle of occipital bone; 9, anterior nasal aperture; 10, on the lachrymal bone in the inner wall of the orbit; 11, malar bone, near its junction with the zygoma; 12, superior maxilliary bone; 13, ramus of the lower jaw; 14, body of the lower jaw, near the mental foramen.

The bones of the skull, with the exception of the lower jaw, are immovably united together where they come into contact by the form of articulation known as a *suture*. These sutures

are often dentated or serrated in outline (see Fig. 12); the serrations strengthen the junction between the two bones. When it is desired to study the shape of the skull-bones

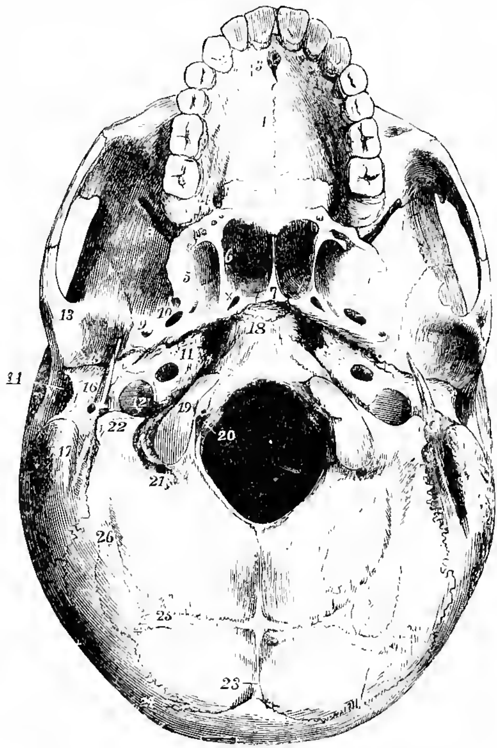


FIG. 13.—External base of the skull. (Allen Thomson.) $\frac{1}{2}$

1, palate plate of the superior maxillary bone; 2, palate plate of the palate bone; 7, vomer bone; 12, jugular foramen; 13, articular eminence of the temporal bone; 14, external auditory meatus; 15, glenoid fossa; 18, basilar process of the occipital bone; 19, condyle of the occipital bone; 20, is placed in the foramen magnum; 23, external occipital crest running down from the protuberance; 24, superior curved line of the occipital bone; 25, 26, inferior curved line.

separately, the skull must be disarticulated or separated into its constituent bones; but it is impossible to describe here in detail all these various bones.[1]

[1] For such a description, see Quain's "Anatomy," vol. ii. pt. 1.

The cranial bones, by their union, form a hollow case of bone for the protection of the brain; the cavity so formed is rounded or spheroidal above but is flatter at its base. The base is further divided by ridges of bone into three hollows, or fossæ,

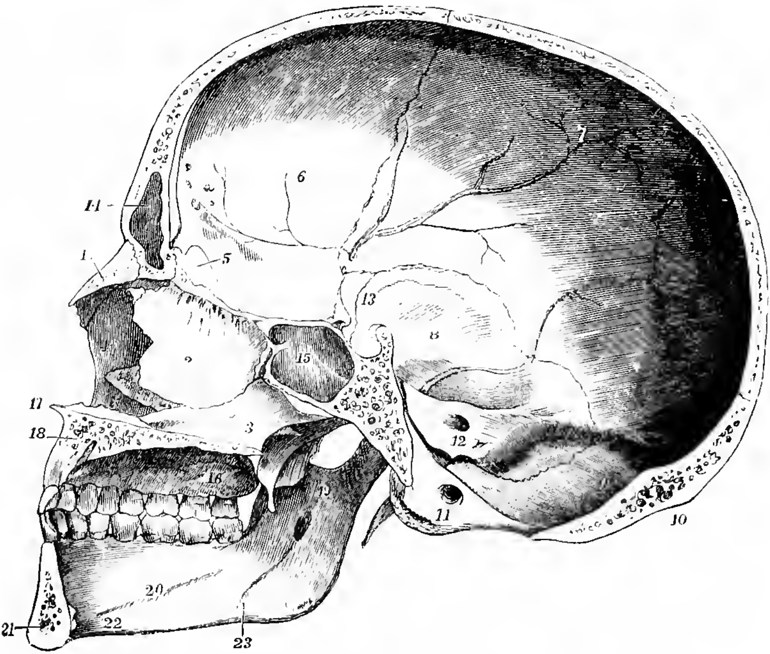


FIG. 14.—Section of the adult skull a little to the left of the median plane. (Allen Thomson.) ½.

1, nasal bone; 2, perpendicular plate of the ethmoid bone with olfactory foramina and grooves at its upper part; 3, vomer; 6, inner surface of the frontal bone; 7, of the parietal bone; 8, squamous part of the temporal bone; 9, on the occipital bone below the internal occipital protuberance; 10, external occipital protuberance; 17, anterior nasal spine; 19, on the inner surface of the ramus of the lower jaw, below the sigmoid notch, and above the inferior dental foramen.

which correspond to divisions of the brain; the posterior fossa lodges the *cerebellum*, or lesser brain; the middle and anterior fossæ conform to the shape of the base of the greater brain, or *cerebrum*. Besides smaller holes, or foramina, for the passage of nerves and blood-vessels to and from the brain, the base of

the cranium contains a larger opening, the *foramen magnum* (see Fig. 13), through which the portion of the central nervous system called the medulla oblongata passes, uniting brain and cord. The bones of the face form the greater parts of the orbits for the accommodation of the eyes, the nose, the hard palate, the upper and lower jaws. The outline of the nose is completed by the nasal cartilages. The nasal bones and the cartilages completing the nose may be felt through the skin during life; the flexible front portion is cartilage, the fixed part behind is formed by the nasal bones. The hard palate, or roof of the mouth, is formed by the superior maxillary bones, which also bear the teeth of the upper jaw. It is continued back, in life, by the fleshy *velum*, or *soft palate*, behind which the *posterior nares*, or inner openings of the nostrils, communicate with the pharynx.[1] The prominences of the cheek are formed by the malar bones.

The lower jaw (*inferior maxilla*) is the only bone in the skull which has a movable articulation. A section through this joint has already been given as an example. We may now consider somewhat more fully the movements which take place at this joint. The lower jaw is capable of movement both upwards and downwards, backwards and forwards, and from side to side. These movements are necessary to give a grinding action between the teeth.

The movements of the jaw are brought about by several muscles; the strongest set are those which raise it and bring it into contact with the upper jaw, against the resistance of anything which may be interposed. The jaw is depressed by its own weight, but may be forcibly lowered by the action of special muscles, the chief of which are the digastries, attached beneath the jaw in front and running backward parallel to the line of the jaw on each side (see 12, Fig. 15).

When the jaw opens the condyle and interarticular cartilage are pulled forward, as you may find by applying your forefinger to the articulation just in front of the external opening of the

[1] The pharynx is the upper funnel-shaped part of the alimentary canal which leads to the gullet, or œsophagus; into it the mouth and the windpipe, or trachea, also open.

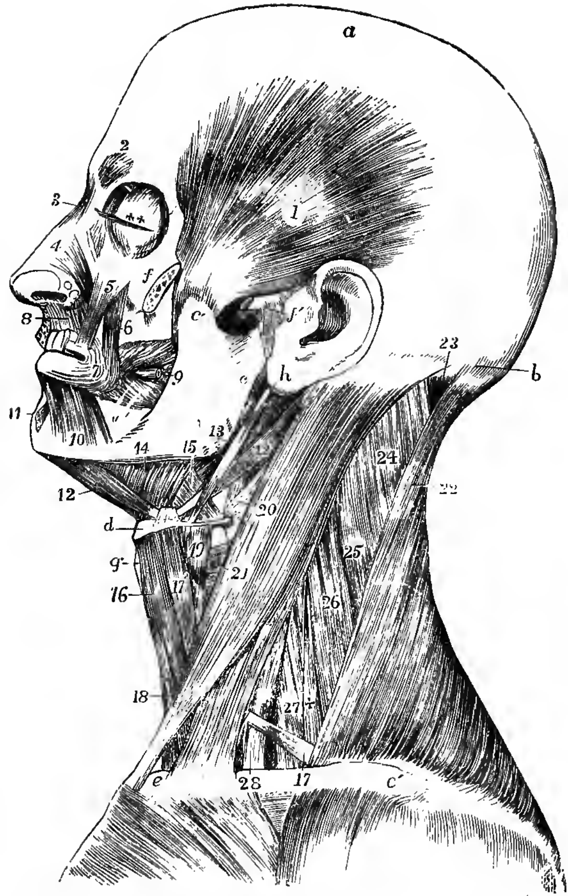


FIG. 15.—Deep muscles of the left side of the head and neck. (Allen Thomson, after Bourgery.) $\frac{1}{3}$

a, vertex of head; *b*, superior curved line of occipital bone; *c*, ramus of lower jaw; *c′*, its coronoid process; *d*, hyoid bone; *e*, sternal end of clavicle; *e′*, acromial end; *f*, malar bone divided to show the insertion of the temporal muscle; *f′*, divided zygoma, and external ligament of the jaw; *g*, thyroid cartilage; *h*, placed on the lobule of the auricle, points to the styloid process; 1, temporal muscle; 2, corrugator supercilii; 3, pyramidalis nasi; 4, compressor naris; 5, levator labii superioris; 6, levator anguli oris; 7, outer part of the orbicularis oris, the part below the nose has been removed; 8, depressor alæ nasi; 9, points to the buccinator muscle, through which the parotid duct is seen passing; 10, depressor labii inferioris; 11, levator menti; 12, 12, anterior and posterior bellies of the digastric; 13, stylo-hyoid muscle; 14, mylo-hyoid; 15, hyoglossus, between which and 13 is seen a part of the stylo-glossus; 16, sterno-hyoid; 17, on the clavicle, indicates the posterior, and 17′, the anterior belly of the omo-hyoid; 18, sterno-thyroid; 19, thyro-hyoid; 20, 21, on the sterno-mastoid muscle, point, the first to the middle, the second to the lower constrictor of the pharynx; 22, trapezius; 23, upper part of the complexus; 24, 25, splenius; 26, levator angulæ scapulæ; 27, middle scalenus; +, posterior scalenus; 28, anterior scalenus.

ear; the same thing happens when the lower jaw is forcibly moved forward. If one forefinger be placed in this position on either side, and the jaw be then moved from side to side laterally, it will be found that one condyle moves forward while the other remains in the groove. These movements are brought about by the action of the external pterygoid muscles, shown in the drawing (Fig. 16). When these muscles contract together on the two sides, the jaw is drawn forward; when they contract alternately, the jaw is moved from side to side.

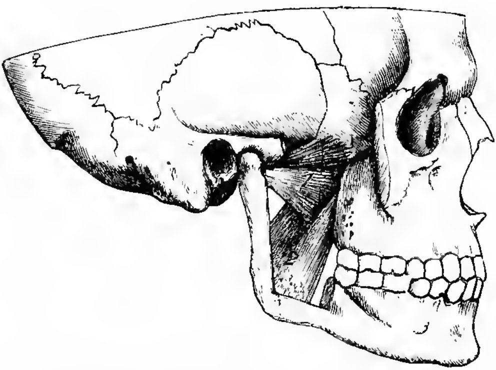


FIG. 16.—The pterygoid muscles from outside. (G. D. T.) ⅓. (Quain's "Anatomy.") The masseter muscle, the greater portion of the zygomatic arch, the temporal muscle with the coronoid process, and a large part of the ramus of the jaw have been removed. 1, external pterygoid; the figure is placed on the lower head; 2, internal pterygoid.

The strong set of muscles which raise the lower jaw comprise, on each side, the internal pterygoids (2, Fig. 16) on the inner side of the jaw, the masseters outside, and the temporals above (see 1, Fig. 16). The action of the temporal and masseter muscles may be felt through the skin. The temporal, above and in front of the ear (on the temple), may be felt to contract by its swelling up as the jaw is moved upwards from an open position; the masseter may be similarly felt at the angle of the jaw, if the teeth are ground together after the jaw is closed.

Each jaw is armed with a number of teeth, for the purpose

of grinding or *masticating* the food. The full number of teeth in the adult is sixteen in each jaw. The teeth are symmetrical in character in each jaw, and in each side of each jaw. Of the eight in each half of each jaw, the two nearest the front (front teeth) are called *incisors*, or cutting teeth; the next is the *canine* tooth, which is longer than the others, and is used for piercing hard food; the remaining five are grinding teeth, and are more or less flat-topped, but provided with cusps or eminences, so as to give an uneven surface serviceable for grinding. The two nearer the front of these five are transitional in character, and are called *bicuspids;* the other three are the *molar*, or "true molar" teeth. During mastication the food is kept under the teeth by the action of the muscles of the cheeks and tongue, which return it from either side as it becomes displaced by the previous action of the jaw, so replacing it between the teeth.

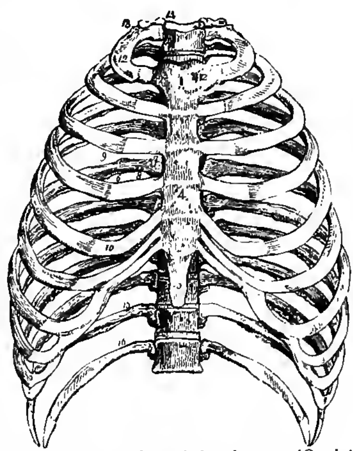


FIG. 17.—Front view of the thorax. (Quain's "Anatomy.")

1, manubrium; 2, is close to the place of union of the first costal cartilage; 3, clavicular notch; 4, body of the sternum; 5, ensiform process; 6, groove on the lower border of the ribs; 7, the vertebral end of the ribs; 8, neck; 9, tuberosity; 10, costal cartilage; 12, first rib; 13, its tuberosity; 14, first dorsal vertebra; 15, eleventh rib; 16, twelfth rib.

THE THORAX.

The bony framework of the chest, or thorax, may be regarded as a kind of open basketwork of bone, which gives stability and elasticity to the outline of this upper compartment of the trunk, and at the same time, when acted upon by appropriate muscles, allows the volume of the chest cavity to be rhythmically altered in the act of breathing, and so occasions air to pass into and out of the lungs, which occupy the greater part of the space inside.

The bony thorax, as shown in the woodcut, is formed by

the twelve thoracic vertebræ, and by the twelve ribs on each side (twenty-four in all), and is completed in front by the rib cartilages, which are attached to the sternum, or breast-bone, lying in the mid line in front.

The thorax is shaped like a rounded and truncated cone, and is much longer behind than in front. The ribs at first slope backwards from their attachments to the vertebræ, and thus give rise to the hollow in the middle line of the back; they then curve round forward in the rest of their length, so completing the posterior and lateral wall of the thorax. In this latter part of their course the ribs slope downwards. In front the ribs are articulated with the costal cartilages, which unite them to the sternum, in the manner shown in the woodcut.

This bony framework is in the body converted into a closed box by soft tissues. Two sheets of muscles called the intercostals (see Fig. 18) lie between the successive ribs, their fibres passing obliquely from the one rih to the other. The floor of the cavity of the thorax is formed by a large sheet of muscle and tendon, called the *diaphragm*, which is attached all round the lower border of the thorax, and has a strong central tendon. The diaphragm completely shuts off the upper cavity of the trunk (*i.e.* the thorax) from the lower cavity or abdomen. It is pierced at its centre and posterior part by the tubes and vessels which must pass from one cavity to another. These are the great blood-vessels carrying the blood to and from the lower part of the body, and the *œsophagus*, or tube which conveys the food to the stomach.

It must be remembered that the ribs are free to move to a certain extent up and down, around their attachments to the vertebræ as an axis. Since the ribs slope downward, anything which raises them must make them stand out more at right angles to the vertebral column, and hence must increase the capacity of the chest by increasing its girth. The increase takes place both from before backward and laterally. The raising of the ribs takes place through the contraction of those layers of intercostal muscles which are known as *external*, because they lie nearer the skin than the other layer, which are called the *internal* intercostals. The external intercostals are

shown in the accompanying figure in the upper intercostal space. In the lower space, the external intercostals have been represented as removed, so as to show the internal intercostals. A glance at the direction of the muscle fibres of the external intercostals in the figure will show that when these fibres shorten, the ribs to which they are attached must together

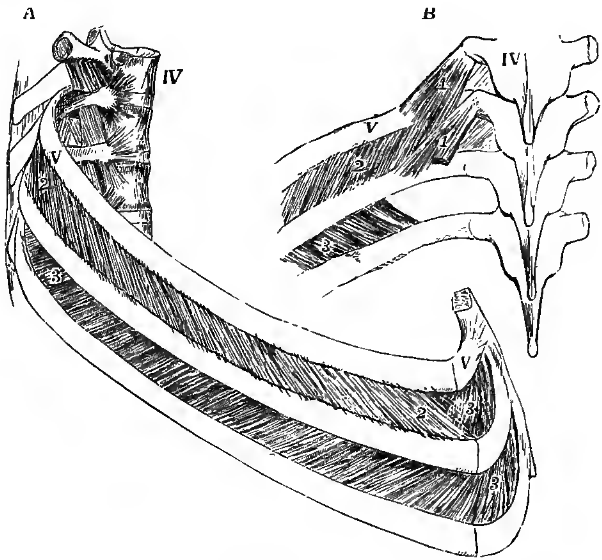


FIG. 18.—Intercostal muscles of the fifth and sixth spaces. (Allen Thomson, after Cloquet.) $\frac{1}{3}$

A, from the side; B, from behind.

IV., fourth dorsal vertebra; V, V, fifth rib and cartilage; 1, 1, levatores costarum muscles, short and long; 2, 2, external intercostal muscle; 3, 3, internal intercostal layer, shown in the lower space by the removal of the external layer, and seen in A in the upper space, in front of the external layer: the deficiency of the internal layer towards the vertebral column is shown in B.

move upwards.[1] The action of the internal intercostals, the fibres of which slant in the opposite direction in forced expiration, is to lower the ribs. In ordinary breathing the weight of the chest is, however, sufficient. The internal intercostals are

[1] The first rib is held fixed by the muscles above it; and hence when the external intercostals contract movement upwards must take place.

continued between the rib cartilages in front, and *as these slope upwards* this portion of the internal intercostals will tend to raise the cartilages and so aid in inspiration.

The action of the ribs is not the only means by which the capacity of the thorax is altered; it has in the diaphragm a movable muscular floor. The diaphragm is not a sheet lying all in one plane (see Fig. 52); it is somewhat dome-shaped, the top of the dome being turned towards the thorax, and hence, when the muscular sheet which forms its peripheral part contracts, the dome is drawn down towards the abdomen, thus increasing the capacity of the thorax from top to bottom. Thus, if at the same time the ribs are raised and the diaphragm contracted, the dimensions of the thorax are increased in all directions.

Breathing by the action of the ribs is spoken of as *costal* respiration, and breathing by the action of the diaphragm as *diaphragmatic* or *abdominal* respiration.

The increase and diminution in the volume of the thorax causes a quantity of air alternately to enter and leave the lungs, which fill the greater part of the thoracic cavity; for the increase in volume causes a suction on the contents of the thoracic cavity. Now, the lungs are the only organs within the thorax which can expand to the necessary extent and prevent the formation of a vacuous space inside. The lungs can expand in this manner because they consist essentially of air-chambers with elastic walls, to which the ultimate subdivisions of the windpipe, or trachea, lead. When the thorax increases in volume, the atmospheric pressure blows the air down the trachea and distends these air-chambers so as to fill the increased space, thus increasing the volume of the lungs and bringing a supply of air to them. On the contrary, when the ribs fall and the diaphragm rises, the capacity of the chest diminishes, air is forced out, and the air-spaces in the lungs become less distended. The purpose of this *respiration* or alternate sucking of air in (*inspiration*) and blowing it out (*expiration*) we shall learn subsequently.

THE PELVIS.

The bony pelvis (see Fig. 19) is a strong ring of bone formed by the union of the two hip-bones with the sacrum; this receives the weight of the upper part of the body and transmits it to the thigh-bones. The thigh-bones articulate with the hip-bones in two deep cups, one on each bone, called the *acetabula* (see Figs. 19 and 20).

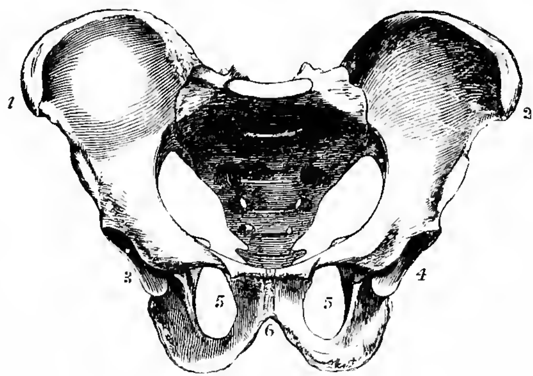


FIG. 19.—Adult male pelvis seen from before, in the erect attitude of the body. (Allen Thomson.) $\frac{1}{4}$

1, 2, anterior extremities of the iliac crests; 3, 4, acetabula; 5, 5, thyroid foramina; 6, subpubic angle or arch.

When the ligaments and muscles attached to the pelvis are present, it forms a basin-shaped cavity, the floor of which supports to a certain extent the contents of the abdominal cavity (*abdominal viscera*).

Each hip-bone (*os innominatum*) is originally formed from three distinct bones, which persist in youth but become fused together in the adult (eighteenth to twentieth year). The three bones are named *ilium*, *ischium*, and *pubis* respectively; the ilium is the upper and larger part of the bone which articulates with the sacrum and extends down to form part of the acetabulum; the pubis lies in front, and unites with its fellow to form an arch (*the pubic arch*); the ischium is the lower

portion of the bone, that on which one rests in the sitting posture. These names for the different parts of the bone are

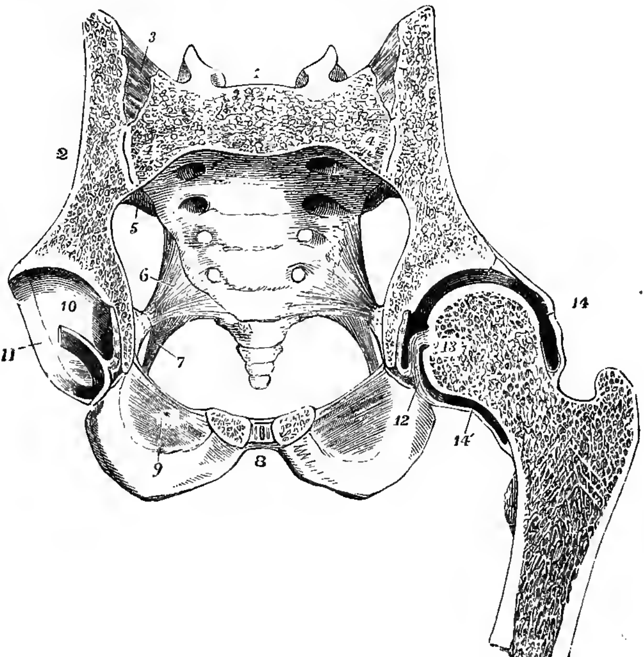


FIG. 20.—Transverse oblique section of the pelvis and hip-joint, cutting the first sacral vertebra and the symphysis pubis in their middle, from a male subject of about nineteen years of age. (Allen Thomson.) $\frac{1}{3}$

1, first sacral vertebra ; 2, ilium ; 3, posterior sacro-iliac ligament ; 6, small sacro-sciatic ligament ; 7, great sacro-sciatic ligament ; 8, placed in front of the symphysis pubis, in the cut surface of which the small median cavity, the adjacent cartilaginous plates, and the anterior and posterior ligamentous fibres are shown ; 10, cartilaginous surface of the cotyloid cavity, through the middle of which the incision passes transversely, dividing the interarticular ligament and the fat in the fossa acetabuli ; 11, cotyloid ligament ; 12, interarticular ligament connected with the transverse part of the cotyloid ligament ; 13, placed on the cut surface of the head of the left femur near the depression where the interarticular ligament is attached ; 14, 14, upper and lower parts of the capsular ligament.

still used even after union into one bone has taken place, in order to describe the different regions of the bone. The upper and posterior brim of the pelvis is known as the iliac crest ; it

forms in the body the eminence of the haunches. To the back of the ilium are attached the strong hip muscles (*glutei muscles*) which straighten the leg on the body at the hip joint; they are used, for example, in straightening the body at the hips when rising from a stooping posture, as also in walking and in running. The muscles which flex the leg on the trunk at the hip joint lie in front.

The sacrum and hip-bones are immovably articulated together. Where the two hip-bones meet in front a pad of cartilage is interposed between them, which serves the same purpose as the intervertebral discs in the case of the vertebræ. This junction of the two bones is called the *pubic symphysis*.

The articulation of the thigh-bone with the hip-bone is one of the best examples in the body of what is known as a ball-and-socket joint. A similar kind of joint is found in the shoulder, where the *humerus* (the bone of the upper arm) is joined to the *scapula* (or shoulder-blade); but here the socket is not so deep, and the degree of movement is hence considerably greater. Nevertheless the amount of free movement in every possible direction at the hip joint is very large.

The nature of the ball-and-socket joint is well seen in the accompanying drawing (Fig. 20), showing a section through the hip joint. The round ball-shaped head of the *femur* (thigh-bone) is covered with smooth articular cartilage; as is also the opposed cavity of the acetabulum, except at its bottom where it does not touch. The joint is strengthened, in this case, by a strong ligament uniting the middle of the head of the femur to the bottom of the socket; this is called the *interarticular ligament*. There is as usual a capsule surrounding the joint into which the lubricating synovial fluid is secreted. The joint is further strengthened by strong ligamentous bands which pass over the capsule from hip-bone to thigh-bone.

The Limb Bones.

The bones of the upper and lower limb exhibit a marked amount of similarity, or *homology*, in their arrangement. The shoulder joint corresponds to the hip joint; the humerus, or

arm-bone, articulating with the shoulder-blade, which although so different in shape corresponds to the hip-bone. In the upper arm, as in the thigh, there is but one bone; while in the forearm there are two bones, the ulna and radius, corresponding respectively to the tibia and fibula in the leg. Next there are a number of small bones of the wrist (carpal bones), corresponding to a number of small bones (tarsal bones) in the ankle. More distal to these there are a row of bones, five in each case, called *metacarpals* in the hand and *metatarsals* in the foot. Next are three rows of bones, in each case, forming the fingers and toes respectively; these bones are called *phalanges* (sing. phalanx) both in the hand and foot. In the case of the thumb and great toe there are but two phalanges; the other digits possess three each.

The Upper Limb.

The upper limb is attached to the body by the shoulder-girdle, which consists of two bones—the *clavicle*, or collar-bone, and the *scapula*, or shoulder-blade. The clavicle, as shown in the drawing, is a bone with a double curve somewhat like an italic *f*. It may be felt beneath the skin at the junction of neck and thorax in front. It is articulated to the breast-bone in front, and passes outward and backward to articulate at its other outer end with a process of the scapula called the *acromion process* (see Figs. 22 and 23).

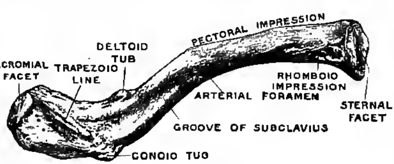


Fig. 21.—Right clavicle, from below. (Drawn by T. W. P. Lawrence for Quain's "Anatomy.")

The scapula is a triangular-shaped plate of bone which is placed at the back of the shoulder, the shortest side of the triangle being directed upwards. Its anterior surface is somewhat concave, following the shape of the underlying parts of the body, and its posterior surface is correspondingly convex. Across its dorsal surface there runs a ridge of bone called the

spine of the scapula, which becomes more prominent as it passes outwards and ends in the acromion process above referred to, where the end of the clavicle is attached.

Beneath the acromion process is the head of the scapula, which replaces the outer angle of the triangle by a rounded or elliptical - shaped articular surface (the *glenoid fossa*) covered with cartilage, against which the head of the *humerus*, or upper arm-bone, moves. The head of the humerus has a spherical surface, also coated with cartilage, and the joint is enclosed by a capsule, so as to make a shallow ball-and-socket joint. The scapula and its processes, together with the clavicle, give attachment to the muscles which move the arm at the shoulder-joint.

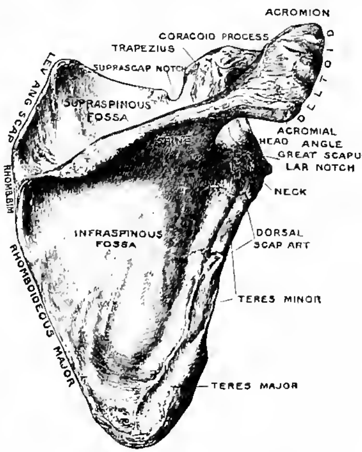


FIG. 22.—Dorsal view of right scapula. (Drawn by T. W. P. Lawrence for Quain's "Anatomy.")

The attachments of the sternum, shoulder-girdle, and humerus are represented in Fig. 23; it may be pointed out that there is a disc of cartilage at the articulation between the clavicle and sternum.

The *humerus*, or bone of the upper arm (see Fig. 24), extends from the shoulder to the elbow; it articulates at the shoulder with the scapula, and at the elbow with the *ulna* and *radius*, the bones of the forearm. The upper extremity of the humerus includes the head, a hemispherical articular surface which, as above described, forms part of the shoulder-joint; the neck, a narrow groove marking off the head from the rest of the bone; and the *great* and *small tuberosities*, which are eminences giving attachment to certain of the shoulder muscles. The shaft or body of the bone bears rough patches on its surface at places where muscles were attached. It is cylindrical in shape above, but triangular below. At its lower extremity the bone

becomes broader from side to side, and has two articular surfaces called the *trochlea* and *capitellum*. These articular surfaces are both convex from before backward; but the trochlea, which articulates with the ulna, is concave from side to side; while the capitellum, which articulates with the radius,

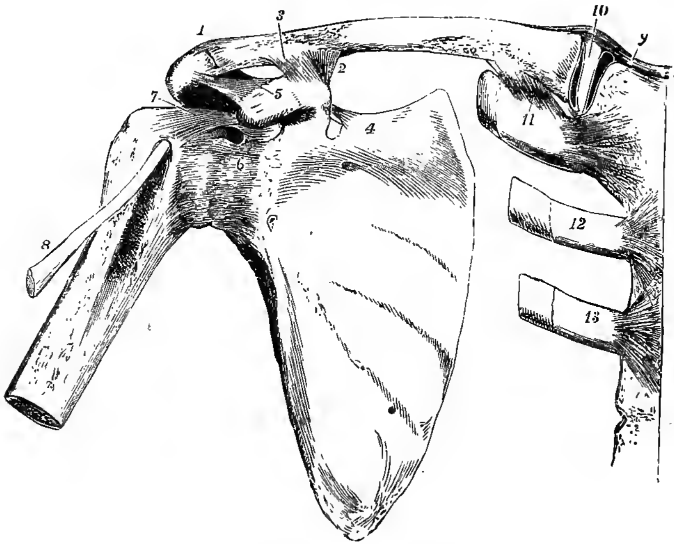


FIG. 23.—View from before of the articulations of the shoulder-bones. (Allen Thomson.) $\frac{1}{3}$

1, acromio-clavicular articulation; 2, conoid, and 3, trapezoid part of the coraco-clavicular ligament; 4, near the suprascapular ligament; 5, on the coracoid process, points to the coraco-acromial ligament; 6, capsular ligament of the shoulder-joint; 7, coraco-humeral ligament; above 6, an aperture in the capsular ligament through which the synovial membrane is prolonged under the tendon of the subscapularis muscle; 8, tendon of the long head of the biceps muscle; 9, right half of the interclavicular ligament; 10, interarticular fibro-cartilage of the sterno-clavicular articulation; 11, costo-clavicular ligament; 12 and 13, cartilage and small part of the second and third ribs attached by their anterior chondro-sternal ligaments.

is convex in this direction also. The upper ends of the ulna and radius bear articular surfaces to match these surfaces on the humerus (see Fig. 25). The surface on the ulna, which articulates with the humerus, is convex from side to side, to suit the concavity in this direction of the trochlea of the

humerus, and correspondingly concave from above downwards. The surface by which the head of the radius articulates with

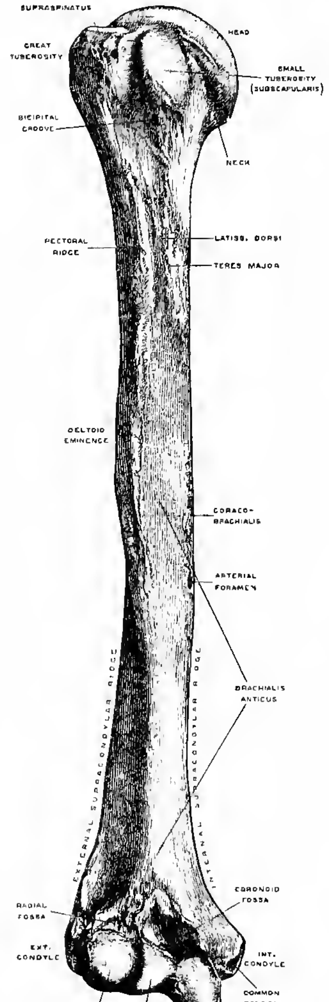


FIG. 24.—Right humerus, from before. (Drawn by T. W. P. Lawrence, for Quain's "Anatomy.")

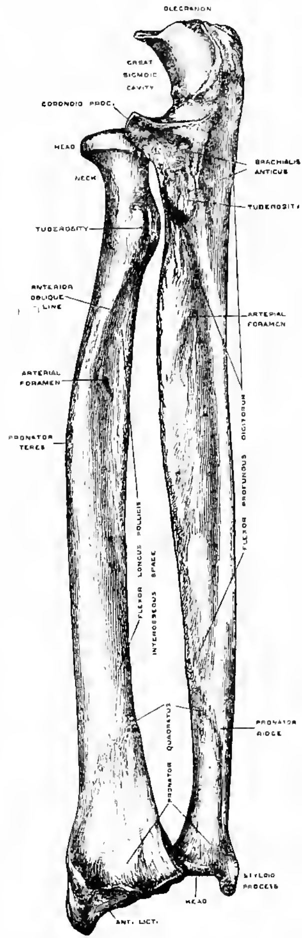


FIG. 25.—Anterior view of the right radius and ulna in supination of the hand. (Drawn by T. W. P. Lawrence, for Quain's "Anatomy.")

the humerus is circular and slightly hollowed out, so as to suit the convexity of the capitellum.

Of the two bones of the forearm (see Fig. 25), the ulna is large at the elbow and tapers towards the wrist; while the radius is smaller at the elbow and becomes more massive at the wrist.

The radius and ulna articulate with each other both at elbow and wrist. The articulations are such as to admit of a rotation of the radius to a certain extent around the ulna. The head of the radius at the elbow is held in position by the *orbicular ligament* (see Fig. 25). Around the head is a smooth articular surface which moves during rotation against a concave facet on the ulna. At the wrist there is a convex articular facet on the ulna, and a concave facet on the radius. The movement of the radius round the ulna brings about *pronation* and *supination* of the hand. In supination the bones are uncrossed; in this position, with the fore-arm held horizontal, the palm of the hand is uppermost. In pronation the lower end of the radius is crossed inwards over the ulna, and the back of the hand is uppermost. In the movement from supination to pronation, rotation takes place at the radio-ulnar articulations, and these are hence termed pivot joints. The movement between the humerus and ulna is purely one of extension and flexion, and this is brought about by the hinge joint formed by these two bones. The elbow joint is hence a compound joint, including both a hinge joint (humerus and ulna) and a pivot joint (radius and ulna).

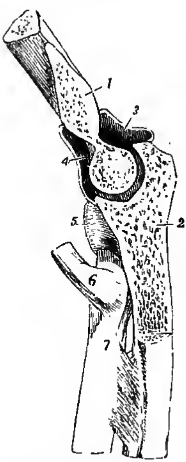


FIG. 26.—Sagittal section of the elbow joint through the great sigmoid cavity of the ulna and the trochlear surface of the humerus. (Allen Thomson.) $\frac{1}{3}$

1, cut surface of the humerus; 2, that of the ulna; 3, posterior part, and 4, anterior part of the synovial cavity of the joint; 5, orbicular ligament; 6, tendon of the biceps muscle; 7, is at the lower end of the oblique ligament.

The movements at the wrist are allowed to take place by a very complicated series of articulations (see Fig. 27), partially

between the radius and three of the carpal bones, and partially between the carpal bones themselves. The ulna takes no part in the wrist joint, being shut off, as shown in the figure (Fig. 27), by a strong ligamentous band. The articular surface of the radius which touches the carpal bones is concave both from before backward and from side to side, and those carpal bones which articulate with it together furnish a correspondingly convex surface.

The carpal bones, as shown in the figure (Fig. 27), are arranged in two rows; synovial cavities are present between them, and there is a considerable amount of gliding motion possible between the first and second rows, but only a slight amount between bones of the same row.

Distally[1] the carpal bones of the second row articulate with the metacarpal bones, which are the bones underlying the palm of the hand. The amount of movement between the metacarpal bones of the four fingers and the carpal bones is not large, although a small amount of movement inward of the fourth and fifth[2]

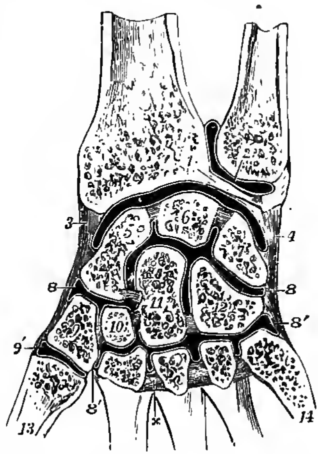


FIG. 27.—Section of the inferior radio-ulnar, radio-carpal, intercarpal, and carpo-metacarpal articulations. (Allen Thomson.) $\frac{1}{2}$

1, triangular fibro-cartilage; 2, placed on the ulna, points to the synovial cavity of the inferior radio-ulnar articulation; 3, external lateral, and 4, internal lateral ligament, and between them the synovial cavity of the wrist; 5, scaphoid bone; 6, lunar; 7, pyramidal; 8, 8, upper portion, and 8′, 8′, lower portion of the general synovial cavity of the intercarpal and carpo-metacarpal articulations; between 5 and 6, and 6 and 7, the interosseous ligaments are seen separating the carpal articular cavity from the wrist-joint; between the four carpal bones of the lower row, and between the magnum and scaphoid, the interosseous ligaments are also shown; the upper division of the synovial cavity communicates with the lower between 10 and 11, and between 11 and 12; ×, marks one of the three interosseous metacarpal ligaments; 9′, separate synovial cavity of the first carpo-metacarpal articulation; 13, first, and 14, fifth metacarpal bone.

[1] The words "proximal" and "distal" are used to denote parts respectively nearer and farther from the central part of the body.

[2] The metacarpal and metatarsal bones are numbered from the thumb

metacarpals takes place in closing the hand. The first metacarpal bone (that of the thumb) possesses a separate synovial cavity (see 9′, Fig. 27) between its proximal end and the bone of the carpus with which it articulates (the *trapezium*). This joint is what is known as a *saddle joint*, the two surfaces concerned being respectively convex and concave in directions at right angles to one another, and fitting against each other saddle fashion.[1] The four metacarpal bones of the fingers are united at their distal extremities by a strong band of ligament (*transverse metacarpal ligament*) which prevents any great movement of these bones with respect to one another, and strengthens the hand. This ligament is shown in Fig. 28, which also shows a front view of the ligaments of the wrist joint.

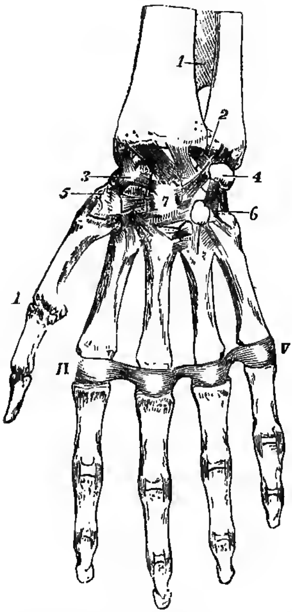


FIG. 28.—General view of the articulations of the wrist and hand from before. ⅓. (Quain's "Anatomy.")

1, lower part of the interosseous membrane; 2, and from that point across the lower end of the radius, the anterior radio-carpal ligament; 3, scaphoid bone; 4, pisiform; 5, trapezium; 6, unciform; 7, os magnum, with most of the deeper ligaments uniting these bones; I, first metacarpo-phalangeal articulation with its external lateral ligament; II to V, transverse metacarpal ligament; in the several interphalangeal articulations of the fingers the lateral ligaments are shown; in the thumb the external only is visible.

The joints between the metacarpal bones of the four fingers and the first row of phalanges (*metacarpo-phalangeal joints*) are termed *condyloid joints*. In these joints the distal ends of the metacarpal bones are convex both from before backwards, and from side to side; while the proximal ends of the first row

and great toe respectively, so are the phalanges (finger and toe bones) of the hand and foot.

[1] A saddle joint is so called because of its resemblance to that made by a horseman with his saddle; it may be represented by holding the thumb

of phalanges are correspondingly concave. There is thus allowed a certain amount of movement in any direction, so that each finger is capable of a certain amount of angular rotation (verify this), as if the joint were a ball and socket.[1] The interphalangeal joints in the fingers are simple hinge joints which allow only bending (flexion) and straightening (extension).

In the thumb the metacarpo-phalangeal joint is a hinge, and not a condyloid, joint, the function of the latter being taken on by the saddle joint described above, between the first metacarpal and trapezium bones. The joint between the phalanges of the thumb is a hinge joint.

The Lower Limb.

The *femur*, or thigh-bone, is the longest bone in the skeleton, and extends from the hip to the knee. Since in the normal standing position, with the feet close together, the knees are also close, while the acetabula into which the heads of the femora are inserted are at opposite sides of the pelvis, it follows that each femur in this position inclines somewhat inward as it descends. At the same time it also inclines slightly backward. The amount of this inclination inwards is greater in woman than in man. The femur (see Fig. 31), for descriptive purposes, is divided into superior extremity, shaft, and inferior extremity. The superior extremity includes the head, neck, and trochanters. The *head* is spherical in shape, forming more than half a sphere, is covered with articular cartilage, and forms the ball of the "ball and socket" of the hip joint. The *neck* is a stout rounded mass of bone connecting the head with the shaft and meeting the shaft at an angle of 125°. The *great* and *small trochanters* (see Fig. 31)

as far as possible from the fingers of the hand and placing the two forks so formed in contact at right angles.

[1] There is this difference, however, between a ball-and-socket and a condyloid joint, that in the former one of the bones, viz. that bearing the ball surface, can rotate in the socket formed by the other; while in the condyloid joint there is no such rotation, the angular rotation being due to a free gliding motion.

are two roughened prominences or ridges of bone situated

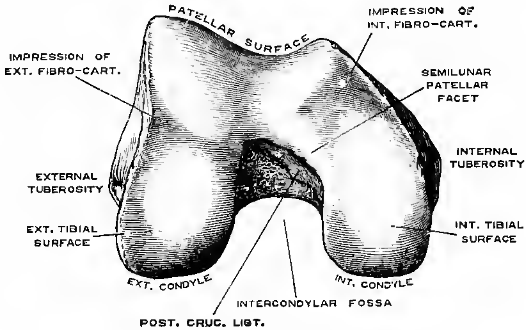


FIG. 29.—Lower extremity of right femur, from below.
(Drawn by T. W. P. Lawrence for Quain's "Anatomy.") $\frac{3}{5}$

where the neck joins the shaft, which serve for the attachment of muscles to the bone.

The *shaft* of the femur is not quite straight, but slightly

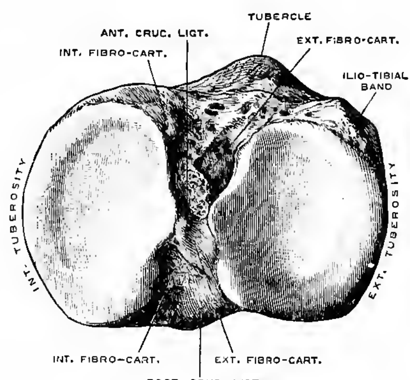


FIG. 30.—Upper extremity of the right tibia, from above.
(Drawn by T. W. P. Lawrence for Quain's "Anatomy.") $\frac{3}{5}$

curved from above downwards, with the convexity forwards. It is nearly cylindrical in section in the middle of its length, but

becomes very much broadened laterally at its lower end, where it passes into the inferior extremity.

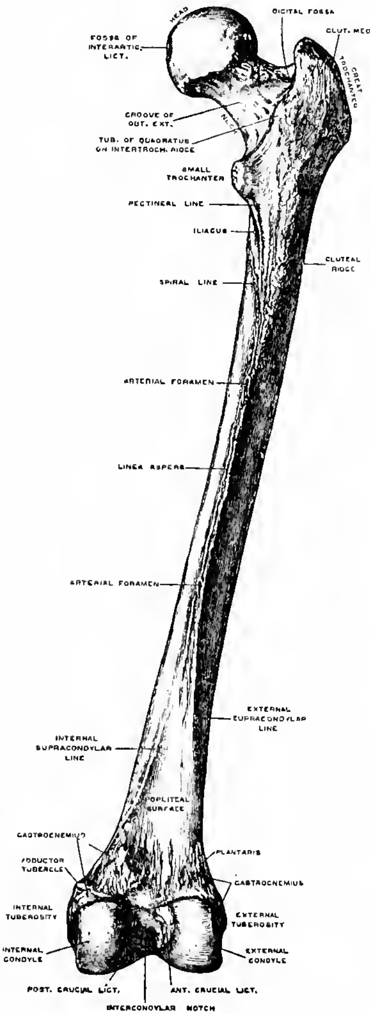


FIG. 31.—Right femur, from behind. (Drawn by T. W. P. Lawrence for Quain's "Anatomy.")

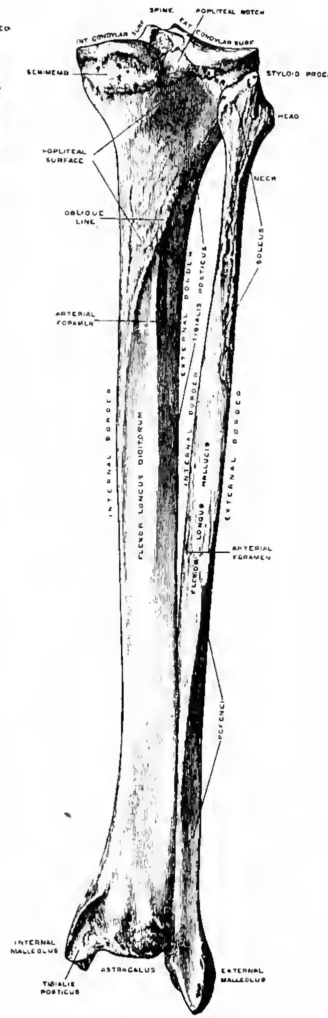


FIG. 32.—Right tibia and fibula, from behind. (Drawn by T. W. P. Lawrence for Quain's "Anatomy.")

The *inferior extremity* (see Fig. 29) is the broadened-out lower end of the shaft; it forms two eminences, called the *external* and *internal condyles*, which are united in front, but separated behind by a notch, or fossa (*intercondylar fosse*). The surfaces of the condyles are convex both from before backward and from side to side, while between them in front is a concave hollow, which extends to some extent up the front of the lower extremity of the bone. All this surface is covered by smooth articular cartilage. The grooved surface between the condyles articulates with the *patella* (or knee-pan), the convex eminences of the condyles with the nearly flat upper articular surface of the *tibia* (shin-bone), and the *semilunar fibro-cartilages* which are the interarticular cartilages of the knee joint.

The articulation of the head of the femur with the hip-bone has already been described (see p. 37). The lower extremity forms part of the knee joint, which is shown, partially in section, in the accompanying figures.

The bones taking a share in the formation of the knee joint are the femur, tibia, and patella. The patella is what is known as a *sesamoid* bone—that is, a bone formed in the tendon of a muscle, usually where it passes over or bends round a bony surface. The patella is shaped like a triangle with rounded off angles, and is placed base upwards just in front of the knee joint in the combined tendons of the extensor muscles which straighten (or extend) the leg at the knee. It serves the double purpose of protecting the knee joint in front and of hardening and strengthening the extensor tendon where this bends round the knee.

Between the opposed articular surfaces of the femur and tibia, which are the two chief bones in the knee joint, are interposed the *semilunar fibro-cartilages*.. These are two crescentic-shaped plates with a free surface both above and below, and are thick at their outer border (which is attached in each case to the capsule of the joint), but thin away to an edge at their inner margin so as to leave part of the upper articular surface of the tibia free in the centre. This portion of the articular surface of the tibia comes in contact with that of the femur. The two ends of each semilunar cartilage are attached to the

non-articular part of the upper extremity of the tibia which is interposed between the two articular surfaces (see Fig. 30).

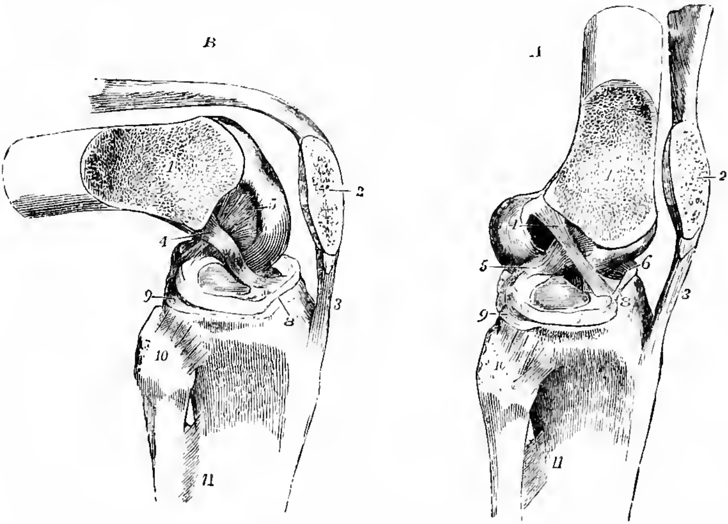


FIG. 33.—The superficial parts of the knee joint removed, and the external condyle of the femur sawn off obliquely, together with half the patella, so as to expose both the crucial ligaments together. (Allen Thomson.) $\frac{1}{2}$

In A, the parts are in the position of extension, in B, that of flexion, the figures being designed to show the different states of tension of the crucial ligaments in these positions. 1, sawn surface of femur; 2, sawn surface of patella; 3, ligamentum patellæ; 4, anterior or external crucial ligament, tense in A, and relaxed in B; 5, posterior or internal crucial ligament, partly relaxed in A, tense in B; 6, internal, and 7, external semilunar fibro-cartilage; 8, transverse ligament; 9, articular surface of the tibia, extending behind the external semilunar fibro-cartilage; 10, on the head of the fibula, points to the anterior superior tibio-peroneal ligament; 11, upper part of the interosseous membrane.

The semilunar cartilages are thus crescent-shaped wedges which adapt the articular surfaces of tibia and femur to each other. In the accompanying figures of the knee joint there are also shown the two crucial ligaments which connect the femur and tibia, and, besides strengthening the union, prevent over-extension.

The movement at the knee is not purely that of a hinge joint, although the effect is much the same; but is a compound of gliding and rolling of the condyles of the femur on the tibia

and semilunar cartilages, accompanied (at the end of extension or beginning of flexion) by a small amount of rotation.

The bones of the lower leg are the *tibia* and *fibula* (see Fig. 32); of these the tibia is the stronger and more massive. It transmits all the weight of the body above it to the ankle, for the fibula takes no part in the knee joint, and the tibia furnishes the greater part of the surface at the ankle joint for articulation with the *astragalus*, that bone of the foot which articulates at the ankle.

The tibia and fibula are of almost equal length, the head of the fibula lying a little lower than that of the tibia at the knee, while the fibula lies a little lower at the ankle. It here forms the *external malleolus*, a prominence of bone at the outer side of the ankle. The corresponding prominence on the inner side is furnished by the tibia, and is known as the *internal malleolus*.

In position, the tibia lies to the inside and somewhat anteriorly to the fibula. The two bones articulate both at their upper and lower extremities; but there is practically no movement at either articulation, so that there is nothing in the leg, corresponding to pronation and supination of the forearm. The tibia and fibula are united by strong interosseous ligaments. The fibula is a long slender bone which serves to strengthen the ankle joint. It furnishes to this joint an articular surface situated on the inner surface of the external malleolus. The fibula gives attachment to some of the leg muscles. Others of these muscles are attached to the tibia and to the lower extremity of the femur; they cause the movements which take place at the ankle joint and those of the foot and toes.

The ankle joint is formed by the tibia and fibula above, and the astragalus beneath. A section across the joint from side to side is shown in Fig. 34, and another from before backward is seen in Fig. 35. The movements are those of *flexion*, in which the foot is bent upwards in front towards the leg, and *extension*, in which the foot is depressed and brought into a line with the leg. The total range of movement is about a right angle.

There are seven bones in the *tarsus* (see Fig. 36), named

respectively: 1, *astragalus*, which forms the lower articulation of the ankle joint; 2, *calcaneum*, or *os calcis*, which lies beneath the astragalus and projects backward to form the heel, to which the *tendo Achillis* is attached conveying the pull of the calf muscles to the foot; 3, *navicular*, or *scaphoid*, which lies in front of the astragalus at the inner side of the foot and articulates with this bone and with the three cuneiform bones which lie in front of it; 4, *cuboid*, which is situated on the outside of the foot in front of the calcaneum, with which, and the fourth and fifth metatarsal bones, it articulates; 5, 6, 7, the *internal*, *middle*, and *external cuneiforms*, which lie in front of the navicular on the inner side of the foot between that bone and the first, second, and third metatarsal bones respectively.

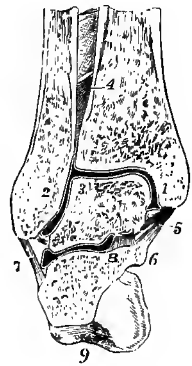


FIG. 34.—Section of the right ankle joint near its middle, and of the posterior astragalo-calcaneal articulation, viewed from before. (Allen Thomson.) $\frac{1}{3}$

1, internal; 2, external malleolus; 3, placed on the astragalus at the angle between its superior and its external surfaces; 4, inferior interosseous tibio-fibular ligament; 5, internal lateral ligament of the ankle joint; 6, sustentaculum tali; 7, calcaneo-fibular or middle part of the external lateral ligament; 8, inner part of the interosseous astragalo-calcaneal ligament; 9, tuberosity of the calcaneum.

The bones of the tarsus, together with the five metatarsal bones, form an arch both from before backward, and from side to side, which is known as the *arch of the foot.*

There is very little movement between the tarsal and metatarsal bones, save a small amount of gliding motion. A small amount of rotation can take place between astragalus and calcaneum.

The chief movement is termed *inversion* and *eversion.* In inversion the outer side of the foot is depressed and the sole turned inward; in eversion the opposite movement takes place.

The movements between metatarsal bones and phalanges and the interphalangeal movements are similar to those of the hand; but the range of movement is somewhat less, especially in the case of the *hallux*, or great toe.

The bones of the foot are shown in the accompanying figures (A and B, Fig. 36).

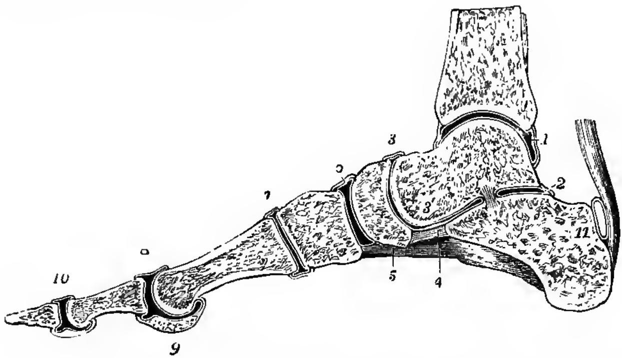


FIG. 35.—Sagittal section of the ankle-joint and articulations of the right foot, a little to the inside of the middle of the great toe. (Allen Thomson.) $\frac{1}{3}$

1, synovial cavity of the ankle joint; 2, posterior astragalo-calcaneal articulation; 3, 3', astragalo-calcaneo-navicular articulation: the interosseous ligament is seen separating 2 from 3'; 4, inferior calcaneo-navicular ligament; 5, part of the long plantar ligament; 6, naviculo-cuneiform articulation; 7, first cuneo-metatarsal articulation; 8, first metatarso-phalangeal articulation; 9, section of the inner sesamoid bone; 10, interphalangeal articulation; 11, placed on the calcaneum, indicates the bursa between the upper part of the tuberosity of that bone and the tendo Achillis.

This brief outline of the structure of the skeleton may be concluded with the following classification of the articulations:—

Articulations are divided into two classes—viz. *synarthroses*, or *continuous* articulations; and *diarthroses*, or *discontinuous* articulations.

In a synarthrosis the bony surfaces are fixed together either directly or by some interposed substance, such as a disc of cartilage. The two most frequent forms of synarthrosis found in the body are the *suture* and the *symphysis*.

The suture is met with only in the case of the skull-bones. In this form of articulation the opposed surfaces of bone practically come in contact, being only separated by a thin layer of fibrous tissue. The edges of the bones where they come in contact are often deeply indented or serrated, so as to firmly interlock with each other. In other cases the edges are thin and bevelled, to meet each other, forming a *squamous* suture; or they may be grooved, forming a *grooved* suture.

In a symphysis the bones are united by a disc of fibro-cartilage which acts as an elastic pad, as has been described in the case of the bodies of the vertebræ and of the two pubic bones.

Synchondrosis is a term applied to growing bones separated by cartilage which afterwards become united; as in the case of

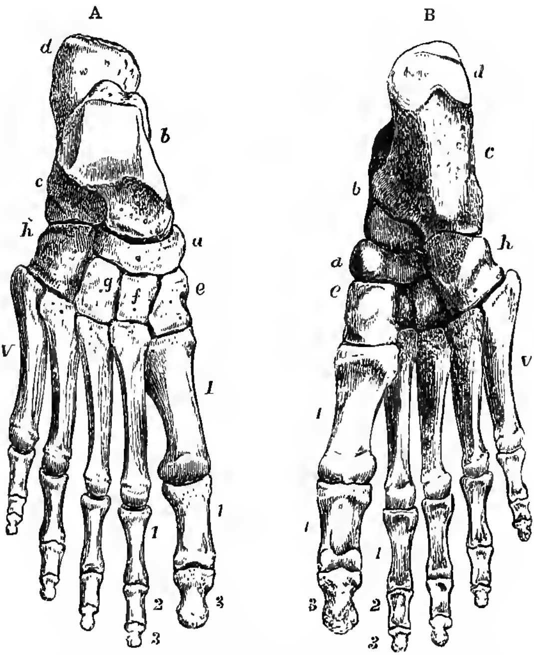


FIG. 36.—The bones of the right foot: A, from above; B, from below. (Allen Thomson.). $\frac{1}{3}$

a, navicular bone; *b*, astragalus; *c*, os calcis; *d*, its tuberosity; *e*, internal cuneiform; *f*, middle cuneiform; *g*, external cuneiform; *h*, cuboid bone; I to V, the metatarsal bone; 1, 3, first and last phalanges of the great toe; 1, 2, 3, first, second, and third phalanges of the second toe.

the three bones which later in life unite to form the hip-bone; and as in the case of the occipital bone at the base of the skull which early in life consists of several distinct bones. As the component bones grow they approach one another, and finally

their edges unite and one bone is formed, the process of union being described as *synostosis.*

Syndesmosis is a term applied when the bones are united by an interosseous ligament, as is the case in the lower articulation between tibia and fibula.

In diarthrosis, or discontinuous articulation, the opposed surfaces of bone remain distinct, they are surrounded by synovial cavities, and there is more or less freedom of movement between them. These are the true joints of the body, and are divided into the following classes:—

1. *Gliding joints* in which the surfaces are nearly flat and capable of gliding to a limited extent over each other; examples are found in the carpal and tarsal bones.

2. *Hinge joints* in which the articular surfaces are arranged to permit a hinge-like movement by which the joint can be straightened (extension) or bent (flexion). One surface is usually pulley-shaped and the other correspondingly ridged. Examples are the articulation between humerus and ulna at the elbow joint and the ankle joint.

3. *Condyloid joints* in which rounded surfaces are present, one being convex and the other concave. Angular movement in any direction is allowed by such a joint, and hence circumduction or angular rotation. The movements of the fingers at the joint between the metatarsal bone and first phalanx illustrate the action of such a joint. Similar joints exist at the corresponding position between the metatarsal bones and the first row of phalanges in the foot.

4. *Saddle joints* in which the opposed surfaces are saddle-shaped (*i.e.* convex in one direction and concave in another at right angles to it) and placed so that the convexity of one is applied to the concavity of the other. Such an articulation is found between the trapezium and the metacarpal bone of the thumb.

5. *Pivot joints* in which one articular surface is either cylindrical or cone shaped, and the other is correspondingly concave, as in the case of the articulation between radius and ulna at the elbow, and that between atlas and axis by means of which the head is rotated (see pp. 22, 42).

6. *Ball-and-socket joints* in which one articular surface is spherical or nearly so, and the other is hollowed out to form a cup to receive it. Examples have been described in the shoulder and hip joints (see pp. 37, 39).

In some cases a joint cannot accurately be described as belonging rigorously to any one of these six classes, as in the case of the articulation of the lower jaw with the temporal bone, where, as already described, there is a *hinge* movement of the condyle of the jaw on the lower surface of the interarticular cartilage, and at the same time a *gliding* movement of the upper surface of the interarticular cartilage forward out of the groove on the temporal bone on to the eminence in front of it. Again, at the knee joint, while the general movement is a hinge one, the motion is accomplished by a mixed motion of gliding, rolling, and rotating.

CHAPTER III.

THE MUSCULAR SYSTEM.

THE jointed bony system, or skeleton, of which the structure has been sketched above, is clothed or covered, except at certain parts where the bones are subcutaneous, by masses of flesh, which are made up of muscles, sheathed in coverings of connective tissue known as *fascia*.

The muscles are masses of soft tissue which are capable of changing their form under the influence of impulses conveyed to them along the nerves from the nervous system. We shall presently see that the muscles are built up of elongated microscopic elements called *muscle fibres*. When the nerve impulse reaches the muscle each fibre *contracts*, or becomes shortened in length, and at the same time thickened so as to preserve an unaltered volume. The result of this is that the muscle as a whole shortens or contracts in the direction of its constituent fibres, and swells up in a direction at right angles to this. The effect of such a muscular contraction will depend upon the attachments of the muscle.

One of the most usual forms of attachment is to two bones, one on each side of a joint. In such a case the muscle is often elongated and spindle-shaped, with a thick middle part forming the belly, and thins out at each end into a fibrous cord or band, called the *tendon* of the muscle.[1] The tendon is strongly attached to the bone, and when the muscle contracts exerts a strong pull upon it. An example of such a muscle is the biceps[2] of the upper arm, which on contracting bends or

[1] A tendon must not be confused with a ligament ; both are fibrous bands, but the tendon is always connected to a muscle at one end, while the ligament is not.

[2] So called because it divides above into two parts.

flexes the elbow joint. The thickening of this muscle as it contracts can be felt as the arm is "put up" or bent at the elbow.

In other cases the muscles are arranged in broad sheets, which sometimes encircle a cavity. Examples of such muscles are the sheets of muscle which form the abdominal wall, and the diaphragm or midriff which separates the thoracic from the abdominal cavity. When these sheets of muscle contract they compress the cavity towards which their concave surface is turned. If the diaphragm contracts, for example, it compresses the contents of the abdominal cavity, unless the pressure is relieved by the relaxation of the muscles of the abdominal wall in front; at the same time, a suction is exercised on the contents of the thoracic cavity, which is relieved by the air entering and filling the lungs. This is the usual action of the diaphragm in breathing, but if both diaphragm and abdominal muscles contract at the same time, the contents of the abdominal cavity are strongly compressed. This simultaneous contraction takes place in the process of *defæcation*, in which, a ring of muscle at the lower end of the intestine being relaxed, any unused detritus of the food which has not been digested and taken into the body is ejected at the *anus* (the lower opening of the alimentary canal) by means of the pressure so exerted.

The muscles connected with the skeleton (*skeletal muscles*) hence vary greatly in form according to the work which they are called upon to perform. A complete description of the skeletal muscles and their actions would fill a greater space than this entire volume, but some idea of their general arrangement may be gathered from the following diagrams and their accompanying descriptions.[1]

All the muscles of the body are not, however, connected with the skeleton. Some form coats lining various tubes of the body, and others are found in various organs. Thus, the heart is a hollow organ containing four chambers, the walls of which are composed of muscular tissue. By its contractions, this muscular tissue alters the volumes of these chambers, and the alteration in volume, aided by an arrangement of valves to be subsequently described, has the effect of driving the blood through the heart and the system of tubes connected with it. The walls of these tubes (the *arteries* and *veins*) are also lined with a muscular coat which alters the bore or calibre of the vessels. This muscular coat is strongly developed in

[1] See also Fig. 15, p. 29.

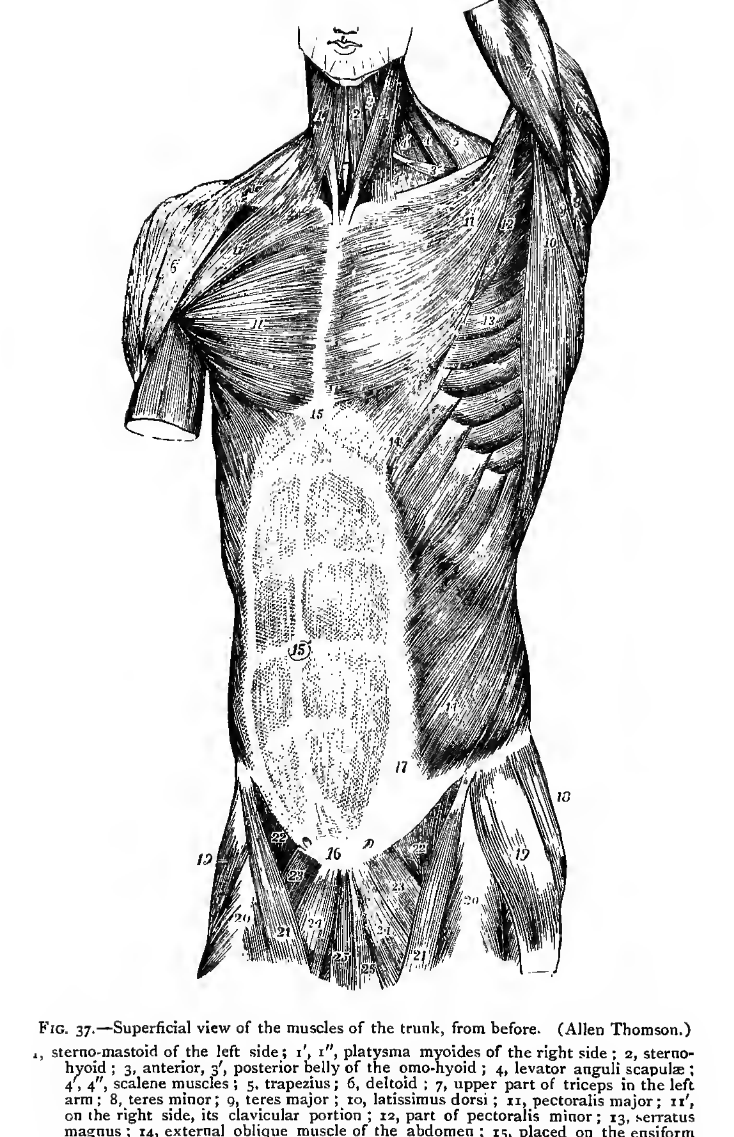
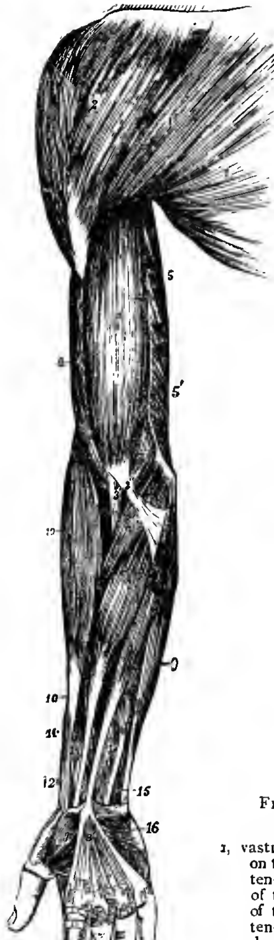


FIG. 37.—Superficial view of the muscles of the trunk, from before. (Allen Thomson.)

1, sterno-mastoid of the left side; 1′, 1″, platysma myoides of the right side; 2, sterno-hyoid; 3, anterior, 3′, posterior belly of the omo-hyoid; 4, levator anguli scapulæ; 4′, 4″, scalene muscles; 5, trapezius; 6, deltoid; 7, upper part of triceps in the left arm; 8, teres minor; 9, teres major; 10, latissimus dorsi; 11, pectoralis major; 11′, on the right side, its clavicular portion; 12, part of pectoralis minor; 13, serratus magnus; 14, external oblique muscle of the abdomen; 15, placed on the ensiform process at the upper end of the linea alba; 15′, umbilicus; 16, is placed over the symphysis pubis, at the lower end of the linea alba; above 16, the pyramidal muscles are seen through the abdominal aponeurosis; 14 to 17, linea semilunaris at the outer border of the rectus muscle, the transverse tendinous lines of which are seen through the abdominal aponeurosis; 18, gluteus medius; 19, tensor vaginæ femoris; 20, rectus femoris; 21, sartorius; 22, femor[illegible] abductor longus; 25, gracilis.



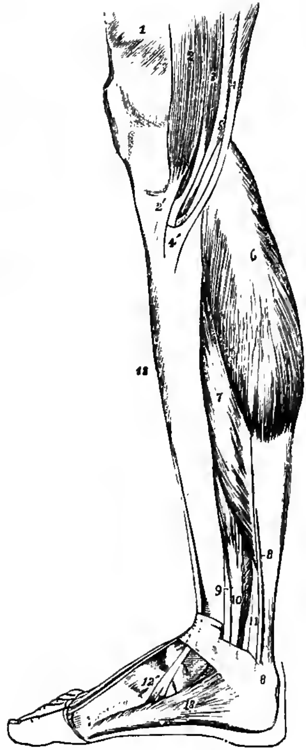


FIG. 39.—Superficial muscles of the leg, seen from the inner side. (After Bourgery.)

1, vastus internus; 2, sartorius; 2′, its tendon, spreading on the inner upper part of the tibia; 3, gracilis; 4, semi-tendinosus; 4′, its insertion; and between 2′ and 4′, that of the gracilis; 5, semi-membranosus; 6, inner head of the gastrocnemius; 7, soleus; 8, 8′, placed upon the tendon Achillis, point to the tendon of the plantaris descending on the inner side; 9, small part of the tendon of the tibialis posticus; 10, flexor longus digitorum; 11, flexor longus hallucis; 12, tibialis anticus; 12′, its tendon of insertion; 13, abductor hallucis.

FIG. 38.—Superficial muscles of the shoulder and upper limb, from before. (Allen Thomson.)

1, pectoralis major, its sterno-costal portion; 1′, its clavicular portion; 2, deltoid, its clavicular part; 2′, its acromial part; 3, biceps brachii; 3′, its tendon of insertion; 3″, its aponeurotic slip; 4, brachialis anticus; 4′, its inner and lower portion; 5, long head of the triceps; 5′, inner head of the same, seen arising from behind the intermuscular septum; 6, pronator radii teres; 7, flexor carpi radialis; 8, palmaris longus, passing at 8′ into the palmar aponeurosis; 9, flexor carpi ulnaris; 10, 10, supinator longus; between 10 and 3′, +, supinator brevis; 11, extensor ossis metacarpi pollicis; 12, extensor brevis pollicis; 13, lower part of the flexor sublimis digitorum; 14, flexor longus pollicis; 15, small part of the flexor profundus digitorum; 16, palmaris brevis, lying on the muscles of the little finger; 17, abductor pollicis.

the smaller arteries, where it is chiefly arranged so that its fibres encircle the blood-vessel. When these fibres contract the bore of the vessel is diminished, and the blood cannot flow so rapidly through it; on the other hand, when the muscle fibres are relaxed the vessel is widened, and the blood can flow through with greater ease.

To these muscle fibres, nerve fibres pass (*vasomotor fibres*), and the muscle fibres are kept in *tone*[1] by impulses sent to them from the nervous system along these fibres. In this way the blood-supply to any part of the body is regulated by the nervous system. The nervous centres have nerve fibres running both to the centre from any part (*afferent fibres*), and from the centre to the part (*efferent fibres*). When any change takes place in the part, a nerve impulse passes to the centre by an afferent fibre, and then a suitable reply is sent back to the part along an efferent fibre. Suppose, for example, a certain set of muscles are set hard at work contracting; then energy is used up rapidly, and an increased supply of blood is required. The nerve centre being informed of this sends nerve impulses down, which relax the muscular coats of the small arteries supplying these muscles, and also stops impulses which had previously been passing down and keeping them constricted, in this way the supply of blood to the muscles is greatly increased. Suppose, again, one commences eating something, saliva is at once secreted, because impulses pass from nerve endings in the mouth up to a nerve centre, and back from there come impulses to the cells of the salivary glands, causing these to secrete. Impulses are also sent to the *arterioles* (small arteries) which supply the glands relaxing these, and giving that bigger supply of blood to the cells which is required by them on account of their increased activity.

Other muscle fibres form coats which line the wall of the alimentary canal; these cause the onward movement of the food undergoing digestion by a kind of contraction called *peristalsis.* This is a wave of constriction which passes along the tube and gradually shifts its contents onward, until what is left unabsorbed during the passage is finally collected in the *rectum* (the last portion of the alimentary canal), from which it is ejected by the act of defæcation as mentioned above.

[1] The tonicity of muscles means the degree of contraction at which they are kept by nervous action. A muscle is never completely relaxed; it is always kept on the alert, as it were, by the nerves supplying it, and when a limb, say, is moved the motion takes place by an increase of this tonicity in one set of muscles, and a diminution in the other opposing set which move the limb in the opposite way.

Similar muscular coats are found lining other vessels in the body, such as the urinary passages. Muscle fibres are also found in the spleen (see p. 92), which they cause to contract at intervals of about once a minute.

Muscle is, then, that tissue in the body which is directly responsible for all movements, but the nature of the movement varies very greatly. In one case it is a movement of a joint causing a change in position of the whole animal; or of part of it relatively to the rest. In another case it is the movement of a fluid, such as the circulation of the blood in the blood-vessels by the contraction of the heart muscle. In another case, the redistribution of the relative supply of blood to different parts by the contraction or relaxation of the muscle fibres surrounding the walls of the arterioles. In yet another case, the passage of food along the alimentary canal by the peristaltic wave of contraction travelling slowly along the tube.

All these varied acts of muscular contraction are carried out under the control of the nervous system; but while some are also under the control of the individual, or, as it is termed, are *voluntary*, others are carried out by the nervous system acting automatically, and are said to be *involuntary*, since they are not under the control of the will.

Muscular tissue is hence divided into two kinds, voluntary and involuntary, and there are other well-marked differences in structure between the two kinds of fibre which will presently be described. Voluntary muscle fibres, for example, when observed under the microscope, are seen to be marked by cross striations—that is, they show markings across them, dividing the fibre into narrow bands, alternately light and dark (see Fig. 41). Such cross striation is absent in involuntary muscle fibre. Hence the terms cross-striated or striped, and plain or non-striated muscle, are often synonymously used instead of the terms voluntary and involuntary respectively. Heart muscle is intermediate between these two kinds in its structure, and is accordingly placed in a class by itself as *cardiac muscle*. It shows cross striation, but less perfectly marked than voluntary muscle. Its contractions are not under the control of the will, so that functionally it is involuntary.

We shall, in the first place, briefly describe the structure of the different kinds of muscle, and then the general mechanics of the movements brought about by the contractions of skeletal muscle.

A skeletal, or voluntary muscle, is enclosed in a sheath of connective tissue, or muscular fascia, which sends in at places sheets of like material to form septa, which divide the muscle into large bundles of fibres. Each of these larger bundles is divided by thinner sheets of intramuscular connective tissue into *fasciculi*, or small bundles, and again, each of these still

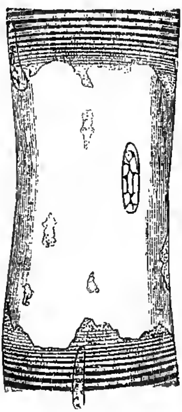


FIG. 40.—Sarcolemma of mammalian muscle highly magnified. (E. A. S., Quain's "Anatomy.")

The fibre is represented at a place where the muscular substance has become ruptured and has shrunk away, leaving the sarcolemma (with a nucleus adhering to it) clear. The fibre had been treated with serum acidulated with acetic acid.

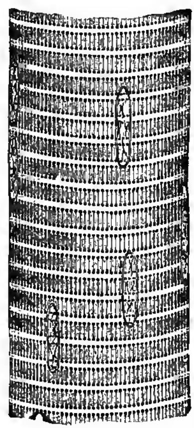


FIG. 41.—Muscular fibre of a mammal examined fresh in serum, highly magnified, the surface of the fibre being accurately focussed. (E. A. S., Quain's "Anatomy.")

The nuclei are seen on the flat at the surface of the fibre, and in profile at the edges.

contains many hundreds of the fine *muscle fibres* which go to make up the chief part of the mass of the muscle. So far the structure can be followed with the naked eye (the fasciculi are the grain which is seen in boiled flesh), but if it be desired to follow the structure further, and see the ultimate fibres of which each fasciculus is made up, the microscope must be employed.

In the fasciculus the constituent fibres lie parallel to one another,[1] each is about $\frac{1}{500}$ of an inch in diameter, cylindrical, or nearly so, in section, and may be an inch or more in length. Each fibre has a sheath, called the *sarcolemma*, which surrounds and incloses the contractile substance. This sheath is so thin and delicate in structure, and so transparent, that it is only seen at places where in the process of preparation the contractile substance within it has been broken across (see Fig. 40). At intervals in the length of the fibre, oval nuclei are to be seen; these become more distinct after the use of staining agents.

The contractile substance[2] is marked off into short dark and light discs, so as to give a striped appearance to the fibre. When the fibre contracts, the light bands disappear, and the dark ones swell out. It is probable that the protoplasm forming the light band in this operation passes into the dark band. The consequence is that the distance from the centre of one dark band to the centre of the next becomes very much lessened, and, as this takes place along the entire length, the fibre as a whole becomes much shorter and thicker.

The sarcolemma passes over the end of the column of contractile substance at each end of the fibre, and becomes continuous with a fine thread of fibrous tissue which passes to form a constituent part of the *tendon* by which the muscle is attached to the bone, and by means of which it pulls upon the bone when it contracts. This attachment of muscle fibre to tendon is best seen when the muscle is plunged into hot water, and afterwards a small shred from the junction between muscle and tendon is taken and teased and examined under the microscope. The hot water causes the end of the contractile material to shrink away from the end of the sarcolemma, as seen in Fig. 42.

The vessels which carry the blood-supply, and the nerve carrying the nerve-supply, generally enter somewhere near the middle of the muscular mass. The artery subdivides into branches within the mass, and finally the small arterial branches (arterioles) break up into capillaries, which run in oblong meshes, as shown in Fig. 43, with the long branches parallel to the length of the muscle fibres. No capillaries ever penetrate any of the muscle fibres; these are nourished solely by diffusion or passage *in solution*, in both directions, between the blood within the capillary and the muscular substance within the sarcolemma, and not by any actual contact between blood

[1] On account of this arrangement of the muscle fibres, a shred of muscle teases with needles more easily in one direction than another, the fibres being more easily separated than broken across. The same is true of nerve in which the nerve fibres lie side by side in a similar fashion. To observe the minute structure of either kind of fibre, a small shred should be teased out as fine as possible, by means of two needles mounted in wooden handles, and then observed under the microscope.

[2] Only an outline of the structure of the contractile substance can be given here; for more detailed information the student is referred to Schäfer's "Essentials of Histology."

and muscle substance. The nutrient materials carried to the muscle fibres by the blood-stream pass out in solution through the thin wall of the capillary vessel, which is formed by a single layer of thin flattened cells (see p. 96). The fluid so separated from the blood, which holds in solution the materials necessary for the life and activity of the muscle fibres, is called the *lymph*. This lymph bathes the muscle fibres, and the nutrient substances

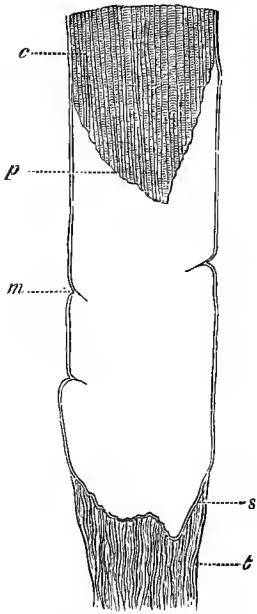


FIG. 42.—Termination of a muscular fibre in tendon. (Ranvier.)

m, sarcolemma; *s*, the same membrane passing over the end of the fibre; *p*, extremity of muscular substance; *c*, retracted from the lower end of the sarcolemma-tube; *t*, tendon-bundle passing to be fixed to the sarcolemma.

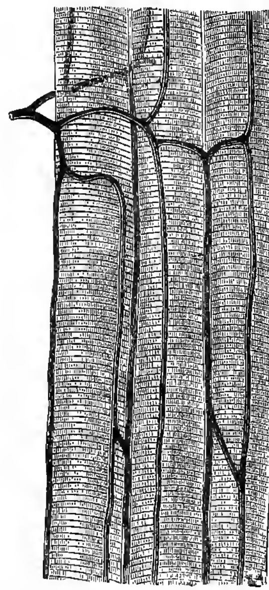


FIG. 43.—Capillary vessels of muscle. (E. A. S., Quain's "Anatomy.")

which it contains pass through the sarcolemma in solution, and are taken up and utilized by the contractile substance. Besides this streaming of nutrient material in towards the muscle substance, there is also a stream in the opposite direction of waste material away from the muscle substance by means also of the intermediate lymph back to the capillary vessels.

In addition to this stream of nutrient substance, which has been in the

first instance formed from the food of the animal, there is also a double stream of gas in solution: of *oxygen*, by means of which the muscle substance is able to decompose or oxidize the nutrient matter and set free the store of energy which it contains, *towards* the muscle substance; and of *carbon dioxide*, a chemical product of this oxidation, and hence a waste product, *away* from the muscle substance and towards the capillaries. The oxygen so required is taken in at the lungs during respiration in a way which will subsequently be described, and at the same time the carbon dioxide is removed from the blood and thrown out with the expired air into the atmosphere (see p. 173).

This mode of exchange between the blood and the tissues, whereby the blood supplies nourishment on the one hand, and removes waste materials, the products of chemical change going on in the tissues, on the other, is the general method throughout the body. The cells of any tissue are not bathed in blood, but in lymph which has exuded through the thin walls of the capillaries ramifying through the tissue. An artery carrying blood penetrates the part, and subdivides, and again subdivides, many times repeated, so giving rise to a large number of very fine branches. As the arterial branches become more minute at each subdivision, their walls also become thinner. Finally, they merge into capillaries, which are very fine tubes *with a diameter of* $\frac{1}{2000}$ *to* $\frac{1}{3000}$ *of an inch*, and with a wall of extreme thinness, consisting of a single layer of pavement epithelium—that is, of thin flattened cells joined edge to edge.[1] Through this thin capillary wall the lymph exudes and bathes the cells which are to be fed by the blood-stream.

The excess of lymph which collects between the capillaries and cells is gathered up by a different system of capillaries, called lymphatic capillaries, which by uniting together form larger lymphatic vessels (see Fig. 45). These larger lymphatics again unite, and finally all the lymph so collected is carried by two main trunk vessels and poured into two large veins of the neck, so returning again to the blood-stream. The lymphatic trunk on the left side of the body is by far the larger of these two, and is known as the *thoracic duct* (see Fig. 44). There is no propelling agent corresponding to the heart in the lymphatic system of man, but the lymphatics are closely beset with valves, which all open in the direction of the thoracic duct, and hence any compression of the lymphatics by muscular movements always determines an onward flow of lymph towards the thoracic duct, and so back to the circulating blood.

The nerve which enters the muscle consists of an immense number of very fine long fibres, which course parallel to one another in the nerve. Within the muscle the nerve subdivides in the same manner as the artery. At each division the number of nerve fibres in each branch decreases, for the individual fibres do not divide, and so at length there are within the muscle a large number of minute nerve twigs, each containing a number of nerve fibres. Each nerve twig supplies a number of muscle fibres. The

[1] See p. 96.

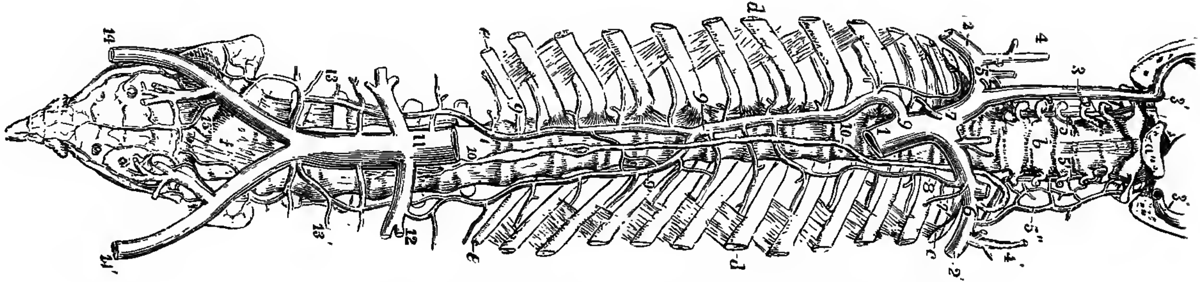


FIG. 44.—Sketch of the principal venous trunks, together with the thoracic duct. (Allen Thomson.) $\frac{1}{8}$

1, superior vena cava divided at the place of its entrance into the right auricle; 2, right, 2′, left subclavian vein; 3, right internal jugular vein; 4, right, and 4′, left external jugular vein; 5, right, and 5′, left vertebral vein; 6, placed on the left subclavian vein below the opening of the last, and of the thoracic duct; 7, 7′, internal mammary veins; 8, the left superior intercostal vein, joining the left innominate, and anastomosing below with the left upper azygos vein; the right superior intercostal vein is seen joining the large azygos vein; 9, 9, 9, large azygos vein; 9′, left lower azygos vein; 10, thoracic duct; 11, inferior vena cava, at the place of junction of the renal veins; 12, communication of the left lower azygos vein with the left renal vein; 13, 13′, right and left ascending lumbar veins, continued upwards into the corresponding azygos veins; 14, 14′, external iliac veins, which are joined higher up by the internal iliacs, to form the common iliac veins.

nerve fibres in a twig finally part company, and each fibre usually branches into two; these branches each pierce the sarcolemma of a muscle fibre near the middle, and end in a small oval-shaped plate of coarsely granular protoplasm, which rests on the contractile substance, and is termed an *end plate.* The nerve impulse arrives at this end plate, and in some manner acts on the contractile substance of the fibre, and causes it to contract. It must not be assumed, however, that all the fibres in the nerve which entered the muscle terminate in this way upon the contractile substance of the muscle fibres. A great number of them do so; but some go to the coats of the arterial branches, and regulate the blood-supply to the muscle in the manner above described; others are sensory or afferent fibres, and instead of carrying nerve impulses to the muscle, carry impulses away from the muscle to the central nervous system.

Cardiac muscle fibres are also transversely striated, but the striations are much less distinct. There is no sarcolemma inclosing the fibre; the fibres branch and the branches unite with those from neighbouring fibres, and the nuclei lie within the contractile substance, and not upon its surface. Each fibre consists of a series of short cylindrical cells united end to end, and the nuclei of the fibre are the nuclei of these cells (see Figs. 46 and 47).

Involuntary or plain muscular tissue differs structurally from voluntary and cardiac muscle in that it does not consist of fibres formed each by the union

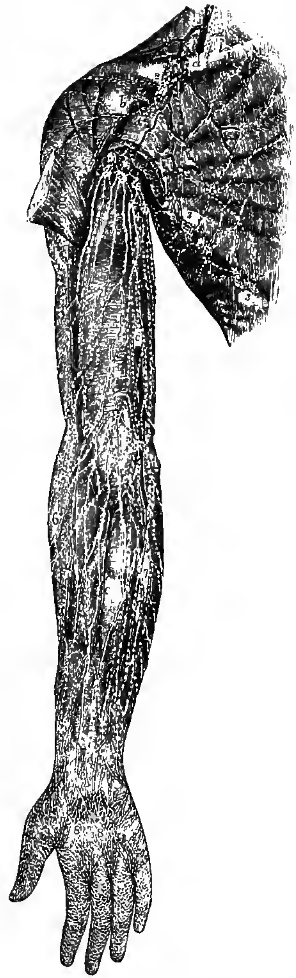


FIG. 45.—Superficial lymphatics of the breast, shoulder, and upper limb, from before (after Mascagni and Sappey).

a, placed on the clavicle, points to the external jugular vein; *b*, cephalic vein; *c*, basilic vein; *d*, radial; *e*, median; *f*, ulnar vein; *g*, great pectoral muscle, cut and turned outwards; 1, superficial lymphatic vessels and glands above the clavicle; 2, infraclavicular glands; 3, 3, pectoral glands; 4, 4, axillary glands; 5, two small glands placed near the bend of the arm; 6, radial lymphatic vessels; 7, ulnar lymphatic vessels; 8, 8, palmar lymphatics.

of a large number of cells, but of single cells. These cells are long and fusiform in shape (Fig. 48), with an oval or rod-shaped nucleus.[1] The cells are longitudinally striated, but show no cross striation (compare Figs. 41 and 48); they are united together by a small amount of connective tissue, and each is surrounded by a delicate sheath, which is, however, invisible unless the contractile material has been broken across.

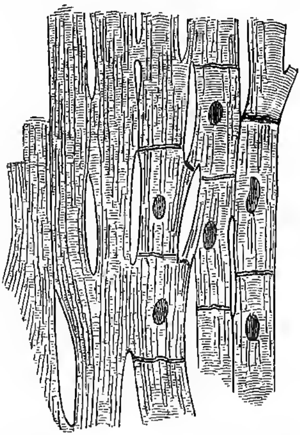


FIG. 46.—Muscular fibres from the heart, magnified, showing their cross-striæ, divisions, and junctions. (Schweigger-Seidel.)

The nuclei and cell-junctions are only represented on the right-hand side of the figure.

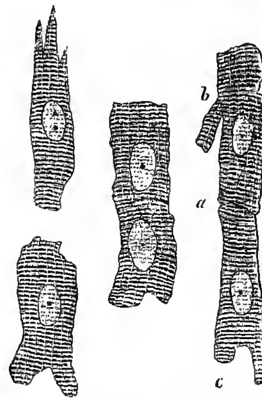


FIG. 47.—Six muscular fibre cells from the heart. (Magnified 425 diameters.)

a, line of junction between two cells; *b*, *c*, branching of cells. (From a drawing by J. E. Neale.)

The different kinds of muscular tissue also vary in the manner of their response on excitation. Under normal conditions in the body, skeletal muscle never contracts except when excited to do so by nerve impulses, which travel to it along the motor (efferent) nerve fibres. The involuntary muscle fibres which line the intestine, and those lying in the substance of the spleen, on the other hand, continue to contract rhythmically even after they have been severed from all their nerve connections. The same is true of heart muscle, for, not only will the entire heart of a cold-blooded animal, such as the

[1] An oval nucleus is seen in the involuntary muscle cells of the muscular coats of the small intestine, and a rod-shaped nucleus in the muscular coats of the larger arteries.

frog, continue to beat for many hours after removal from the body, but even a strip of the muscular tissue, cut out from the heart, and containing no nervous mechanism, will beat for a long time.[1] The mammalian[2] heart ceases to beat soon after removal from the body, but this is due to the more rapid death of the muscle cells, caused by the stoppage of the blood-circulation through them; for, when means are taken to continue the circulation of the blood, even the mammalian heart continues to beat for many hours.

When a skeletal muscle and the nerve passing to it are removed from the body,[3] the muscle can be caused to contract by stimulating its nerve in various ways, such as (mechanically) by pinching or hammering it, (chemically) by applying a crystal of salt to it, or (electrically) by the action of an electric current.

Electric stimulation is the most suitable form for experimental purposes, because the nerve is not injured thereby, and the excitation may be many times repeated. By a certain arrangement of apparatus a graphic record of

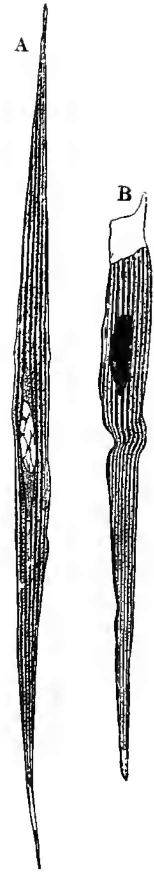


FIG. 48.—Muscular fibre cells from the muscular coat of the small intestine, highly magnified.

A, a complete cell, showing the nucleus with intra-nuclear network, and the longitudinal fibrillation of the cell substance, with finely vacuolated protoplasm between the fibrils; B, a cell broken in the process of isolation; a delicate enveloping membrane projects at the broken end a little beyond the substance of the cell. (E.A.S., Quain's "Anatomy.")

[1] The heart has, in its substance, small groups of nerve cells called *ganglia*, and the purpose of the strip experiment is to show that the rhythmic beating is not due to these nerve cells, but is an inherent property of cardiac muscle, the strip being cut out so as not to include any nerve cells.

[2] The mammalia are that class of animals which suckle their young.

[3] These experiments can best be performed with a muscle and nerve taken from a cold-blooded animal (frog), for a mammalian muscle dies very soon after its blood-supply is stopped.

the response of a muscle to electrical stimulation may be obtained.[1] Induced currents from a secondary coil are made use of, and these are conveyed to the nerve by two wires, called *electrodes*, placed parallel to each other and about $\frac{1}{10}$ of an inch apart. The electrodes are joined up to the terminals of the secondary coil, and the nerve laid across them. On making or breaking the electric current in the primary circuit, a transitory current is induced in the secondary circuit, which excites the nerve and starts a nerve impulse, and this in turn excites the muscle to contract. The muscle is fixed at one end, and its other end is attached by a thread to the short end of a lever. When the muscle contracts the lever

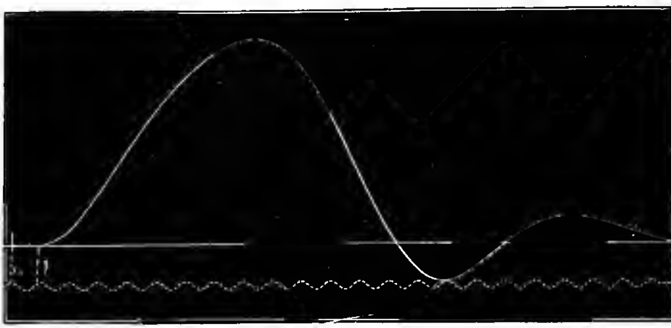


FIG. 49.—Simple muscle curve.

The nerve attached to the muscle was stimulated at *a*, and at *b* the muscle began to contract. The period occupied by the interval between *a* and *b* is termed the "latent period." The lower tracing, taken by a writing-point attached to a vibrating tuning-fork, shows $\frac{1}{100}$ second intervals; the small undulations upon it are due to overtones.

moves, and, by means of a writing-point attached to its long end, traces a curve on a smoked surface of paper which is caused to move past the writing-point.

When a single electric stimulus is applied to the nerve, the tracing obtained of the muscular contraction is similar to that shown in Fig. 49. There is first a very short pause before the contraction begins, called the *latent period*, then the *contraction* begins, and is followed by the *relaxation*. The relative times occupied by the periods of contraction and relaxation vary with the load against which the muscle contracts; but the total period of contraction and relaxation is fairly constant, and amounts approximately to $\frac{1}{10}$ second. If now the stimulation be given rhythmically at regular periods, the effect produced will vary according to the rapidity with which the stimuli or shocks succeed one another. If a small number of stimuli

[1] For details of the methods of obtaining graphic records of muscle contractions, see Brodie, "Essentials of Experimental Physiology."

(4 to 6) per second be applied, each contraction has time to pass off before the succeeding one is evoked, and the result is a series of separate contractions or twitches. If the rate of stimulation be more rapid, each stimulus is applied before the contraction due to the preceding one has passed off, and there is a *summation of effect;* the muscle never becomes completely relaxed, but a sinuous line is traced, due to the muscle being more or less contracted the whole time, the sinuosities being caused by the individual stimuli. With a still more rapid rate of 30 to 40 stimuli per second these sinuosities disappear, and the muscle remains permanently contracted. In this condition each stimulus is thrown in at the height of the contraction due to the preceding stimulus, and so a maximum contraction is maintained. This permanent contraction is known as *complete tetanus*, the imperfect fusion with a slower rate being termed *incomplete tetanus.* The ordinary natural contractions of the skeletal muscles in the body are incomplete tetani; the rate at which the natural nerve impulses are sent to the muscles being about 12 to 14 per second. A muscle cannot be maintained in a tetanized condition for any considerable time, because it becomes fatigued and gradually relaxes, although the nerve does not become fatigued and the impulses are still conveyed along it. Even single stimuli repeated at somewhat longer intervals than $\frac{1}{10}$ of a second are sufficient to fatigue a muscle when the stimulation is long continued.

Both cardiac muscle and involuntary muscle have a much longer latent period than voluntary or skeletal muscle. This may be shown, in the case of involuntary muscle, by exposing the intestine in an animal which has just been killed, and directly stimulating it by pricking with a sharp point. The intestine contracts at the point touched, but only after an obvious delay apparent to the eye.[1]

Cardiac muscle further differs from voluntary muscle, in that it *cannot be tetanized.* The muscle fibres possess naturally the property of contracting at regular intervals. Just after each contraction, the fibres pass into a refractory condition, and cannot by any stimulation be caused immediately to contract. If this tendency to rhythmic contraction has by any means been so much weakened that the contractions do not take place spontaneously, then stimulation may reinforce it, and cause contractions at intervals; but by no means can rapidly repeated rhythmic stimuli be summated, and the heart muscle sent into tetanus. After a contraction has taken place, the fibres become inexcitable for a brief period, and relax, in spite of stimulation. The rate at which the contractions take place

[1] The latent period of voluntary muscle is much too short to be appreciated in such a manner.

can, however, be altered by stimulation, either of the heart muscle directly, or through its nerves.

There are two nerves which carry impulses to the heart, and alter its rhythm (*i.e.* rate of beating); these nerves are branches, respectively, from a nerve called the *vagus*, and from a chain of nerves called the *sympathetic*. The vagus branch slows the heart when stimulated,[1] and if sufficiently strongly excited stops it for a time, *but only for a time;* afterwards the inherent property of contracting which the cardiac muscle fibres possess asserts itself, and no matter how strong the stimulus, the accumulated tendency to contract becomes too strong for the inhibiting [2] stimulus, and the heart recommences to beat slowly.

The sympathetic branch, on the other hand, increases the rhythm when it sends impulses to the heart, causing the heart to beat much more rapidly.[3]

The cardiac muscle fibres then possess the property of rhythmic contractility, and retain this property even when cut off from all nerve mechanism; and, further, stimulation through nerves, or otherwise, can only alter the rate of this rhythmic contraction, and not altogether remove it, either by keeping the fibres permanently contracted or permanently relaxed.

This property of rhythmic contractility is shared to a less perfect degree by the involuntary muscle fibres of the spleen and intestine, but is not possessed at all by voluntary muscle, which only contracts when stimulated to do so. The normal or natural excitation to contraction of voluntary muscle is given by nerve impulses, which are sent out from the central nervous system at a rate of 10 to 12 per second, and cause the muscle to pass into incomplete tetanus.

[1] This effect may be shown experimentally by cutting these nerves, and then stimulating, in each case, the end next to the heart.

[2] Inhibition means the stoppage of any normal action by nervous mechanism; the stoppage of the heart, or its slowing, by the vagus as described above is an example. In consequence of this action the *vagus* is said to be the *inhibitory nerve of the heart.*

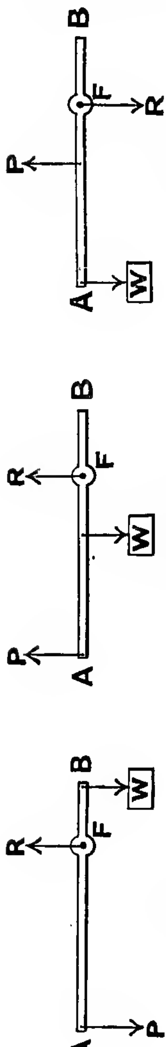
[3] This may be shown by stimulating the cardiac branch of the sympathetic.

A single skeletal muscle rarely or never contracts alone in the manner described above, but always in consort with a number of other muscles. For even the simplest movements require the combined action of several muscles to carry them out. Also, if the movement is at all complicated, the different muscles involved in it must contract in a definite order and time with regard to one another, and with a definite strength of contraction. This harmonious working of the muscles together is spoken of as *co-ordination*. Unless the co-ordination be perfect the movement will be performed in a clumsy and imperfect way. Complicated movements requiring much co-ordination, such as walking, talking, and grasping and handling objects, are learnt *by practice* by the infant just in the same manner as other skilled movements, such as writing, piano-playing, cycle-riding, rowing, swimming, and countless other such accomplishments are learnt later in life. When once any such complicated movement has been learnt it becomes *automatic*, the will is only concerned in starting or stopping the cycle of muscular contractions, and the various movements are carried out in perfect co-ordination or rotation by lower nerve centres, without the attention being consciously fixed upon them. If certain parts of the nervous system be injured, however, this co-ordination is interfered with, some of the paths of nerve discharge become blocked, and the process has to be learnt again ; if, indeed, the injury has not been such as to block all possible paths for the carrying out of the necessary movements. For example, an injury to a certain part of the brain may affect the speech, so that certain words cannot be said at will, because the injury has blocked the track of communication between certain nerve cells in the brain and the muscles of the tongue and lips, of which the movement is necessary for the production of these words. Such words may be acquired again by the establishment of communication through some more roundabout route, as the result of practice or repeated trial. This is but one example. In nearly all cases where any part of the brain is injured, the *paralysis* or loss of function which at first appears as a result gradually vanishes, even though the injury remain permanently, because other parts of the brain take on the work of the injured part. There is a free choice of paths along which nerve impulses may pass from the central nervous system to the muscles, and the usual one is merely the easiest, most convenient and most used one. If this is shut off, a new one is soon discovered. Just as with our present intricate meshwork of telegraphic communication over the world. When communication is interrupted between two important places, there is only a temporary hitch, for soon it is discovered which is the next easiest line of connection between the two places.

The Mechanics of the Skeletal Movements.

The bones form levers which the muscles attached to them are capable of moving. A lever is a rigid bar capable of

turning about a fixed point called the *fulcrum* under the action of forces applied along its length at different points. Any number of forces may act on the same lever, but usually the simplest case only is considered of two forces acting in opposition and balanced by their resultant acting at the fulcrum. One of these forces is usually the pull of the earth on a body, and is known as the *weight* (W), while the opposing force is called the *power* (P).



First order. Second order. Third order.

FIG. 50.—The three orders of levers.

The arrows show the directions of the forces acting on the lever AB, of which F is the fulcrum. The force of reaction (R) at the fulcrum is, in the case of the first order, equal to the sum of the other two (P and W); in the other two orders, to their difference.

It is usual to divide levers into three orders or classes, according to the disposition with regard to one another of fulcrum, power, and weight; but this division is an arbitrary one, for the principle is the same in all three orders. The three orders are figured in the accompanying sketch; in the first order the fulcrum is in the middle, and the weight and power at opposite sides; in the second, the fulcrum is at one end, and the power at the other, the weight being in the middle; while in the third, the fulcrum is still at one end, but the power is in the middle and the weight at the other end.

When the power and weight balance each other, there exists a simple relationship between their magnitude, each being *inversely* proportional to its distance from the fulcrum. That is to say, if P, for example, is three times as far from F as W is, it will only require to be one-third as great to balance it. If P exceed by a little this amount, the weight (W) will be raised while P descends; but the matter will be equalized in this way, that *P will go down three times as far as W goes up.*

The ratio of W to P is called the *mechanical advantage.* This can have any value in the first order, but must be greater than unity in the second, and less than unity in

the third.[1] The fact that P can be made much less than W is an advantage *in one respect only*, viz. that a small force can be made to lift a large weight, but in order to do so the small force must move through a correspondingly greater distance. The force multiplied by the distance is called the *work done*, and in all cases the work done by P equals that done on W.

In the body it is usually less of an advantage to have a small force acting through a long distance than to have a large force acting for a small distance. The muscles and their tendons are very strong, and the tendons are usually inserted closer to the fulcrum than the weight or load to be raised; as, for example, in raising the forearm. Hence a large range of movement is obtained with a small amount of contraction of the muscle, to pay for which advantage the pull of the muscle through its tendon must be many times greater than the weight to be raised. If the biceps muscle were attached halfway out along the radius instead of near the elbow joint, the amount of contraction of its fibres in order to bring the forearm from the extended to the flexed position would be enormous, and, in fact, impossible for muscle fibres as constituted in the body. Hence the insertion is near the elbow joint, and a smaller and correspondingly more powerful pull on the tendon accomplishes the purpose.

Examples in the body of levers of the first order are the movements of the head on the atlas, and of the trunk at the hip joints.

A good example of the second is raising the body on tiptoe; here the toes and metatarsal bones lie at the fulcrum, the weight is at the ankle joint, and the power is applied through the tendons of the calf muscles at the back.

The third class is by far the commonest in the movements of the body; it is seen in the movements at the jaw, in flexion of the elbow and knee joints, and in many movements of the other joints.

This classification of levers has been given here in deference to established custom, but it should be remembered that there is no essential difference between the different

[1] The second and third orders interchange when it is equal to unity, for then P and W are applied at the same point of the lever.

orders, and that the classification has no importance save as a means of description. The essential feature in the lever is that the force may be diminished if its leverage is increased. But this involves increased movement, and although for many mechanical purposes this may be advantageous, in the body it is a decided disadvantage, and hence extent of contraction is economized by increasing the applied force. It should also be remembered that in the body the tendons do not pull parallel to the weight in many cases, and hence the pull on the tendons is still further increased. It follows that the tendons of muscles must be exceedingly tough and strong structures, and this is actually the case, the larger tendons being capable of standing without breaking a pull many times greater than the weight of the body.

The erect position of the body can only be maintained when the vertical line through the centre of gravity falls within an area drawn to include the soles of the feet; but this is not all that is necessary to the maintenance of the erect posture. The joints must be stiffened by a balancing of forces due to a definite amount of tonic contraction[1] in the muscles situated before and behind them. This balancing of forces is learnt in infancy, and afterwards is always maintained, when we assume the erect position, without conscious effort or attention. The activity of the nerve centres is necessary for the maintenance of the erect position; hence a shock to the nervous system, say by a blow on the head, or a sudden fright, causes the person to fall down in a heap. The nervous impulses which kept the various sets of muscles tonically contracted are stopped, the muscles relax, the body is in a position of unstable equilibrium, bending at the joints takes place, and the person falls to the ground.

The same thing is seen in nodding of the head as a person falls asleep in a sitting posture; the muscles at the front and

[1] The term "tonic contraction" means a certain amount of passive or continuous contraction that a muscle is kept in under given conditions. A muscle, even when not undergoing active contraction, is never completely relaxed, but the tendon is kept taut and ready for action, so that there is no slack in the tendon. The same is true of involuntary fibres surrounding blood-vessels, etc., which are always in a more or less contracted condition.

back of the neck, the tonic contractions of which had previously balanced one another, become relaxed, and the head usually falls forward, because the mass of the head in the normal sitting position lies more in front of the articulation between skull and atlas than behind it. Sound sleep in a standing position, or walking during sound sleep, are impossible because of this relaxation of the muscles through inhibition of the tonic constricting nerve impulses to them. In cases where people walk or talk in their sleep the nervous system is not at rest to the normal amount of sound sleep. The same is true in the case of dreaming; portions of the brain which ought to be in a resting condition are active. Even in the soundest sleep, however, there is not complete quiescence of the entire nervous system; the respiration must be kept up throughout by the activity of certain nerve cells, situated in a part of the central nervous system known as the medulla oblongata (see p. 223), which rhythmically send out impulses to the respiratory muscles and cause these to contract. The rhythm of the heart is also probably regulated during sleep by the nerves which pass to it; but, generally speaking, nervous and muscular activity are reduced to a minimum, in order to allow these two tissues, which are continually in action during the waking hours, to become refreshed and recuperated by the nutrient blood-stream, which carries them fresh supplies and removes their waste products.

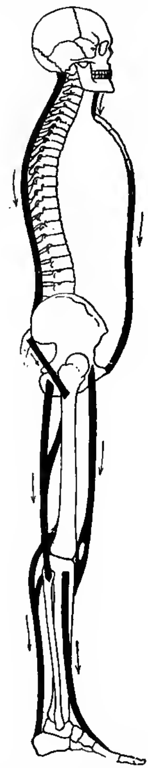


Fig. 51.—Diagram showing the action of the chief muscles which keep the body erect.
The arrows show the direction in which the muscles pull. Those in front oppose and balance those at the back. (Furneaux's "Physiology.")

The muscles which by their balanced tonicity support the body in the standing position are diagrammatically shown in Fig. 51. The muscles in certain positions are aided by ligaments which come on

the stretch in the standing position. Thus, at the knee, the bones are completely extended by the extensor muscles of the thigh, and motion forward is prevented by the ligaments of knee joint.

The reader can easily analyze roughly those muscular movements which take place in the acts of walking and running. When a person starts to walk from a standing posture the weight is first thrown on one foot by a slight movement of the body to that side, then the other foot is raised from the ground and carried forward by a flexion in front at the hip joint and a slight flexion at the knee. At the same time, the other foot is raised on tiptoe by the contraction of the powerful muscles of the calf of the leg, and the whole body is swung forward by a movement at the ankle and hip joints. As this goes on the foot which was raised and carried forward comes on the ground, and the weight is gradually received on it as the body is thrust forward. The other leg is next brought forward by a flexion at hip and knee, and swung out in front to commence another step.

In running, the muscular contractions are more vigorous, and for a brief period during each stride both feet are off the ground. The body is thrown forward just before each foot leaves the ground by a sudden extension of the leg at the hip and knee. In jumping a similar sudden extension, but of both legs at once, is the means of progression.

CHAPTER IV.

POSITION OF THE VISCERA.

THE great cavity of the trunk is divided into two compartments by the diaphragm. The upper compartment is called the thoracic cavity, or *thorax*, and the lower is the abdominal cavity, or *abdomen*. The organs contained in the thorax are termed the *thoracic viscera*, and those in the abdomen the *abdominal viscera*.

THE THORACIC VISCERA.[1]

The thorax contains the heart and the great blood-vessels passing to and from it; the lungs and the branches of the *trachea*, or windpipe, called the *bronchi*, which convey the air to them; the remnants of a gland called the *thymus*, which is relatively large in the infant but becomes gradually insignificant in size towards middle life; part of the *œsophagus*, which is a straight muscular tube serving to convey the food from the mouth to the stomach; the *thoracic duct*, which is a vessel for conveying the lymph (see p. 65) to the position where it joins the blood-stream by opening into a vein in the neck; and various nerves passing either to these organs or on to the diaphragm and the abdominal viscera.

The *heart* is shaped like a cone with rounded apex and base, and is about the same size as the closed fist. It lies in the anterior part of the thorax a little more to the left of the median line than to the right (see Fig. 53). The apex lies opposite to a point about an inch and a half below the left

[1] The student is recommended to accompany this description with the dissection of an animal.

nipple, and three inches from the middle line. Here the apex of the heart touches the thoracic wall as it is thrown forward by each beat, and these beats may be distinctly felt, and in some cases seen through the skin at this point (*the apex beat*). Feeling the heart beat here has given rise to a popular impression that the heart lies much more to the left side than

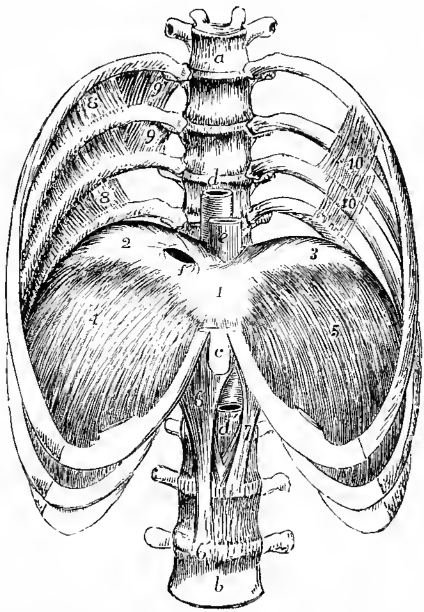


FIG. 52.—The lower half of the thorax, with four lumbar vertebræ, showing the diaphragm from before. (Allen Thomson, after Luschka.) $\frac{1}{4}$

a, sixth dorsal vertebra; *b*, fourth lumbar vertebra; *c*, ensiform process; *d*, *d'*, aorta, passing through its opening in the diaphragm; *e*, œsophagus; *f*, opening in the tendon of the diaphragm for the inferior vena cava; 1, central, 2, right, and 3, left division of the trefoil tendon of the diaphragm; 4, right, and 5, left costal part, ascending from the ribs to the margins of the tendon; 6, right, and 7, left crus; 8, to 8, on the right side, the sixth, seventh, and eighth internal intercostal muscles, deficient towards the vertebral column, where in the two upper spaces the levatores costarum and the external intercostal muscles 9, 9, are seen; 10, 10, on the left side, subcostal muscles.

is really the case; for from this point the heart is directed upwards, and to the right, the base lying above and to the right, so that a small part of the heart lies to the right side of the sternum as shown in Fig. 53. The great vessels which

carry the blood to and from the four chambers of the heart all enter and leave it in a group at the base (see Fig. 54, p. 83). A large vein called the *inferior vena cava* carries the greater part of the blood returning to the heart from the lower part of the body. This vessel penetrates the diaphragm at the back near the vertebral column (see *f*, Fig. 52), and passes up parallel

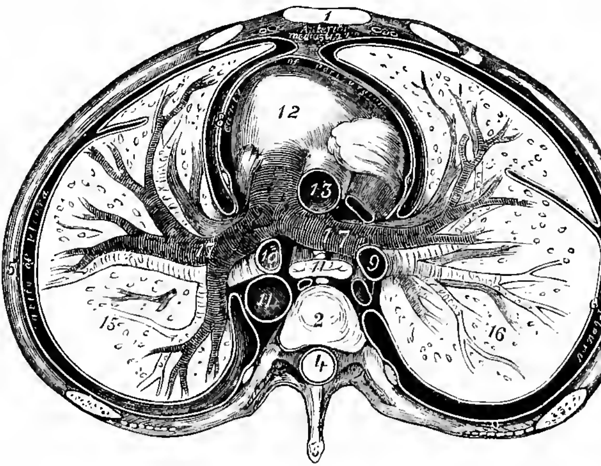


FIG. 53.—Transverse section through the thorax. (Furneaux's "Physiology.") The section is carried above the heart, but below the division of the trachea.

1, sternum; 2, body of dorsal vertebra: 3, spinous process; 4, spinal canal; 5, rib; 6, inner layer of pleura; 7, outer layer of pleura; 8, pericardium; 9, right bronchus; 10, left bronchus; 11, œsophagus; 12, heart; 13, aorta, ascending; 14, aorta, descending; 15, left lung; 16, right lung; 17, pulmonary arteries.

and close to the vertebral column in the thorax to enter the thin-walled right upper chamber of the heart (*the right auricle*). The blood coming from the head, neck, and arms is collected into another great vein (the *superior vena cava*), and by this is also discharged into the right auricle. From the right auricle the blood flows into the right ventricle, being assisted in its flow towards the end when the ventricle is nearly full by the contraction of the auricle, which distends the ventricle.[1] The

[1] For a description of the heart and its valves, see the anatomy of the circulatory system, p. 113; an outline only is given here to enable the student to understand the arrangement of the great vessels in the thorax.

ventricle next contracts, and the communication between auricle and ventricle being closed by a valve opening towards the ventricle, and a communication being opened between the ventricle and a large artery in connection with it called the *pulmonary artery* by the forcing open of a valve directed towards this artery, the blood is discharged under pressure from the right ventricle into the pulmonary artery. The pulmonary artery passes upwards from the heart and soon divides (see Fig. 52) into two branches, one of which passes to each lung and enters at the root, which is situated on the mesial surface of the lung nearer the apex than the base (see Fig. 53). After circulating through the lung, and undergoing certain changes there which will subsequently be described (see p. 173), the blood is collected into the great pulmonary veins which carry it back to the base of the heart, and discharge it into the *left auricle.* By a similar mechanical arrangement to that on the right side, the blood passes from the left auricle to the left ventricle, and from the left ventricle to the aorta.

The *aorta* is the great arterial trunk which carries the blood from the heart to distribute it by means of its branches to the entire system. This great vessel leaves the heart near the middle of the base, and at first passes (see Fig. 54) upwards and to the right (the *ascending aorta*), but soon takes a sharp bend to the left and turns downward (the *arch of the aorta*). In its descending course the aorta (*descending aorta*) lies close to the vertebral column and a little to the left of it. From the convexity of the arch of the aorta there arise the large arteries which carry the blood to the head, neck, and arms (see Fig. 54), viz. the *innominate* artery (dividing into the *right subclavian* and *right common carotid*) for the supply of the right side, and the *left common carotid* and *left subclavian* arteries for the left side. From the descending thoracic aorta various branches are given off, the chief of which are those to the tissue of the lungs called the *bronchial* arteries, and the *intercostal* arteries which pass outwards on each side under each pair of ribs to supply the intercostal muscles. The aorta leaves the thorax at the back of the diaphragm (see Fig. 52), and passes down the abdomen as the *abdominal aorta*, lying immediately in

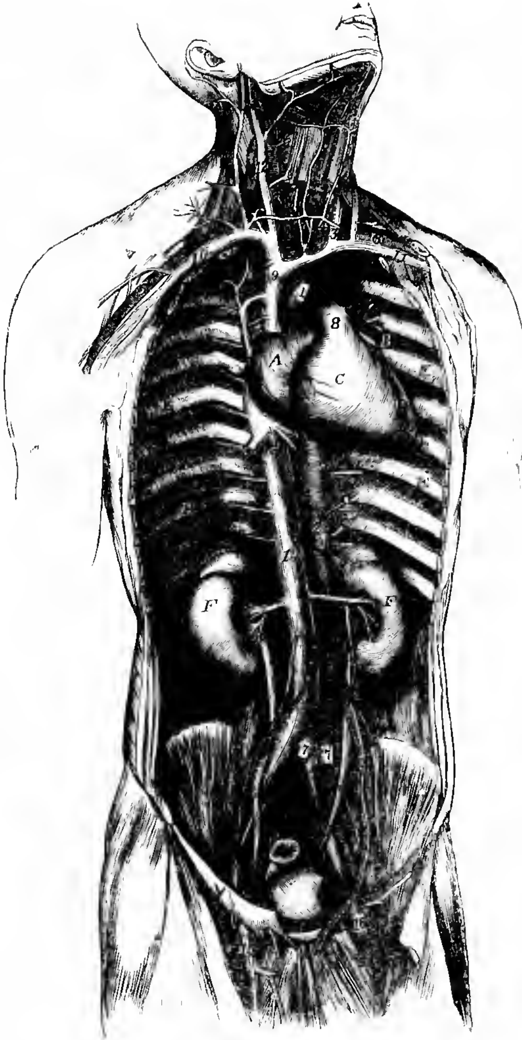


FIG. 54.—General view of the heart and great blood-vessels of the trunk. (Furneaux's "Physiology.")

A, right auricle; *B*, left auricle; *C*, right ventricle; *D*, margin of left ventricle; *E*, ribs; *F*, kidneys; 1, arch of the aorta; 2, descending aorta; 3 and 4, right and left carotid arteries; 5 and 6, right and left subclavian arteries; 7, arteries supplying the lower extremities; 8, pulmonary artery; 9, vena cava superior; 10 and 11, right and left subclavian veins; 12 and 13, right and left jugular veins; 14, vena cava inferior; 15 and 16, veins which collect blood from the lower extremities.

front of the vertebral column. Here it gives off large branches to supply blood to the stomach, spleen, liver, intestines, kidneys, and other abdominal viscera, and finally bifurcates into two large arteries called the *common iliacs*, each of which later divides into two branches, viz. the *internal iliac*, for the supply of the viscera in the lower part of the abdomen (*the pelvis*); and the *external iliac*, which furnishes the chief blood-supply to the leg.

The heart, and the roots of the great blood-vessels arising from it, are surrounded by a strong fibrous bag called the *pericardium*, which is attached below to the diaphragm and above to the great vessels. The inner surface of this bag is lined by a smooth membrane (*serous membrane*). This serous membrane is reflected above over the roots of the great vessels, and is continued all over the outer surface of the heart. There are thus two smooth surfaces opposed to each other, the inner lining of the pericardium and the outer lining of the heart, and between these surfaces friction is reduced to a minimum, as the heart beats within the pericardium. The amount of friction is still further reduced by a fluid (*pericardial fluid*), which is secreted by this inner serous coat of the pericardium and moistens the surface. Besides this function of protecting the heart from friction as it beats, the pericardium is a strong envelope capable of protecting the thin-walled auricles from over distension and injury by any transient engorgement of the heart with blood.

The mouth, or *buccal cavity*, opens posteriorly into a funnel-shaped tube (the *pharynx*) lined by muscular walls, and this tube narrows as it descends in the neck into the *œsophagus*, or gullet (see Fig. 91, p. 182). The œsophagus is also a tube with muscular walls which is collapsed unless when food is passing along it (see p. 182), and in the neck lies behind the trachea, or windpipe. Both these tubes enter the thorax at its apex, but while the trachea soon bifurcates into two branches called the bronchi, one of which passes to each lung, the œsophagus passes straight through the thorax, pierces the diaphragm immediately in front of the aorta, and widens out into the stomach soon after entering the abdomen.

The *thymus* is a small gland resembling in its structure a lymphatic gland, which lies at the apex of the thoracic cavity, surrounding the trachea and in front of it. It is scarcely recognizable as a gland after middle life.

Practically the whole of the remaining volume of the thoracic cavity is occupied by the two lungs, and this fraction of the space greatly exceeds the rest. The lungs are moulded to the shape of the thoracic cavity. The diaphragm beneath, forming the floor of the thoracic cavity, is convex towards the thorax, and the bases of the lungs are correspondingly concave. The diaphragm is placed somewhat lower on the left side, and the left lung is in consequence longer than the right, but it is narrower, and more room is notched out of it than out of the right to accommodate the heart, so that its volume with an equal amount of distension is slightly less than that of the right lung. The outer surface of each lung is convex, to fit the concavity of the thoracic wall. These outer surfaces show in each case a deep cleft or fissure, which begins near the apex at the posterior border and passes obliquely forward and downward to end near the front of the lower margin, thus dividing each lung into two lobes. The right lung, further, has a cleft running horizontally forward from the middle of the oblique one, so that it is divided into three lobes. The inner or apposed surfaces of the two lungs lie against each other except where they are separated by the heart, great vessels, and other structures mentioned above; each inner surface is indented to accommodate these structures. The *apices* of the lungs are somewhat dome-shaped, and extend up to the neck on each side, completely filling up the apex of the thorax. Each lung in a healthy condition is unattached save at the *root* on the inner surface, where the bronchus, pulmonary arteries and veins, and bronchial arteries and veins,[1] as well as certain nerves, enter and leave it.

Each lung is further enclosed in a double-walled bag or

[1] The lung tissue cannot be nourished by the venous blood coming to it from the heart, but must, like the other tissues of the body, be supplied with arterial blood; this is conveyed by special arterial branches given off from the aorta, which are much smaller than the pulmonary vessels, and are called the *bronchial arteries*.

sac, called the *pleura*. One layer of this pleura is closely applied to the inner wall of the thorax, and at the root of the lung this layer is reflected over the outer surface of the lung, forming a second layer which is applied to the lung and closely invests it. These layers of the pleura are exceedingly thin, and during life there is practically no space between them, the lungs distending with each inspiration and filling the whole space. But if an opening of any considerable size be made in the wall of the thorax, the outer layer adhering closely to the thoracic wall is cut through in the process, the elasticity of the distended lung comes into play, the lung shrinks and air is drawn in between the folds of the pleura. The rhythmical enlargement of the thorax by the action of the respiratory muscles is now incompetent to draw air into the lungs. Instead of the air entering and leaving the lungs, it merely passes in and out through the artificial opening in the thoracic wall, and the animal soon *suffocates* and dies unless some means be taken to blow air in and out of the lungs. Although the lungs throughout life, being always less or more distended, have ever this tendency to shrink in volume and leave the thoracic wall, they cannot do so, because a vacuum would be thereby formed. The thorax is an air-tight cavity, and as its volume is rhythmically altered in respiration, air must alternately pass into and out of the lungs. Hence, in a normal condition of the animal, during life there is a *potential* space only between the two layers of each pleura. The pleura is hence a thin double-walled closed sac, both layers of which lie in contact with each other surrounding the lung and continuous round its root. A *very* small amount of fluid (*pleuritic fluid*) is normally secreted between the two layers of the pleura and acts as a lubricant; but in diseased conditions of the pleura (such as pleurisy) the amount of this fluid may become enormously increased, and the two layers of the pleura be widely separated by it. Since the volume of the thorax is limited, any large accumulation of fluid in such a position becomes dangerous, because the lungs collapse to a corresponding extent. Finally, the animal dies, if the condition be not relieved, by *suffocation or asphyxia*, for it is evident that a

point can be reached when it is impossible to suck air into the lungs by distension of the thorax in presence of such an accumulation of fluid between the layers of the pleura.

The Abdominal Viscera.

The viscera contained in the abdominal cavity include the lower and by far the larger portion of the alimentary canal, the liver, the spleen, the pancreas, the suprarenal bodies, the kidneys, and the bladder. In addition to these there are several large lymphatic glands; certain folds of connective tissue which suspend or attach the viscera in their various positions, and carry the blood-vessels which supply them with blood; the abdominal aorta and inferior vena cava, passing along parallel and close to the vertebral column behind; certain nerve centres or ganglia and nerves passing to and from them for the innervation of the viscera; and, in the female abdomen, the internal generative organs, consisting of the uterus or womb, with its appendages, and the ovaries.

These soft viscera are not so thoroughly protected by a complete bony framework as are those of the thoracic cavity, nor is this necessary in the case of the abdomen. Strong broad sheets of muscle passing from the margin of the bony pelvis below to the lower ribs above form a sufficient protection. There is no need to rhythmically change the capacity of the abdominal capacity as there is in the case of the thorax, for there is here no respiratory organ, like a lung, into and out of which air must alternately pass. Further, a complete bony framework surrounding the abdomen would impede the action of the diaphragm by fixing the position of the abdominal viscera. When the diaphragm contracts, it forces down the contents of the abdomen, thus enlarging the volume of the thorax and sucking air into the lungs; the abdominal muscles in front relax, and allow room for the abdominal viscera by an increase in the dimensions of the abdomen from front to back. Thus the sheets of abdominal muscles furnish just the needed kind of support to the abdominal viscera, yielding, yet firm, and suited to the other requirements of the case. Although the volume of the abdominal cavity does not vary with a quick rhythm, like that of the thorax, yet it does vary very considerably from time to time, being distended somewhat after each meal, on account of the increased volume of stomach and intestine. Here, again, the muscular walls are suited admirably for playing their required part; by relaxing they can yield the increased volume, and by an increased tonicity they can become more contracted, and give a uniform degree of support when the volume diminishes.

The inner surface of the abdomen, including the under surface of the diaphragm, is lined by a thin smooth delicate

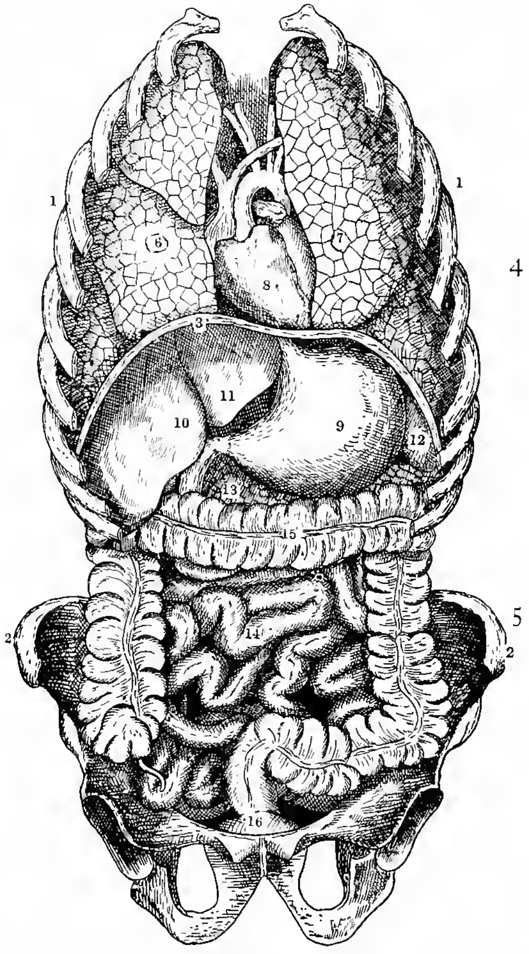


FIG. 55.—The viscera of the thorax and abdomen, viewed from the front. (Furneaux's "Physiology.")

1, ribs, the front portions of which, together with the sternum, have been removed; 2, bones of the pelvis; 3, diaphragm; 4, thorax; 5, abdomen; 6, right lung; 7, left lung; 8, heart; 9, stomach; 10, right lobe of the liver; 11, left lobe of the liver; 12, spleen; 13, pancreas; 14, small intestine; 15, large intestine; 16, bladder.

serous membrane called the *peritoneum.* This smooth membrane is further reflected over both surfaces of the stronger membranes which suspend the organs (when these do not lie on the wall of the cavity), and over the organs themselves, thus forming a very complete smooth investment for all the organs. A small amount of fluid is secreted, which wets the surface of the peritoneum, and has that same function as a lubricant which has been pointed out in the case of several other similar secretions.

On removing the abdominal wall in front, the lower part of the *liver* is seen *above and to the right side.* But the greater part of this organ lies beneath the lower ribs, being moulded to the concavity of the diaphragm, against which its upper dome-shaped surface fits, and from which, and the abdominal wall behind, it is suspended by strong folds of connective tissue coated with peritoneum, termed ligaments. It is divided by a fissure into a right and left lobe, of which the right is the larger. On the right side additional fissures further separate the right lobe into smaller lobes, called the *quadrate*, *Spigelian*, and *caudate* lobes. The *gall bladder*, which temporarily receives the bile secreted by the liver before it is poured out into the intestine, is situated in a depression on the under surface of the right lobe (see Fig. 81, p. 158).

The *stomach* lies *lower down and to the left of the liver*. Its exact position and the extent to which it is visible on opening the abdominal cavity, depend upon the amount to which it is distended by food, but the greater part of it is usually concealed by the ribs and the liver. Its upper surface touches the diaphragm, and it is to some extent suspended from this structure by the œsophagus. It is further held in position by ligamentous bands called *omenta*, which connect it with the liver, intestine, and spleen. The stomach is an enlarged portion of the alimentary canal, which holds the food for a time after a meal, until it can gradually be passed into and along the lower part of that canal, called the *intestine*, or *bowel.* During this stay in the stomach part of the food is acted on chemically by a fluid secreted by certain glands imbedded in the inner layer of its walls (see p. 146). After a

time the food is forced on, out of the stomach and into the intestine, by the contraction of muscular fibres which lie in the stomach walls external to this glandular layer. The junction of œsophagus with stomach, called the *cardia*, is kept closed unless when food is passing in, by a ring of muscle called a *sphincter*. A similar sphincter guards the passage from stomach to intestine (*pylorus*), and the food does not pass continually from stomach to intestine, but only at intervals, when the pyloric sphincter is relaxed and the muscular coats of the stomach contract on the contained food.

A double fold of connective tissue coated with peritoneum, called the *great omentum*, hangs down like an apron from the lower surface of the stomach, and usually conceals the greater part of the intestine. The front fold of this loop turns backwards underneath, and is continued as a back fold, which passes up and is attached to the transverse colon (*vide infra*). On removal of the great omentum, the arrangement of the parts of the intestine can be more clearly seen.

The intestine, by differences in structure and arrangement, is divided into two distinct parts, the small and the large intestine; but for descriptive purposes the small intestine is further divided into three parts, termed the *duodenum*, *jejunum*, and *ileum* respectively, which are structurally much alike; and the large intestine is similarly divided into *ascending colon*, *transverse colon*, *descending colon*, *sigmoid flexure*, and *rectum*.

The small intestine is much the longer portion of the alimentary canal, and measures in man, on the average, about twenty feet. The first ten to twelve inches of its length form a U-shaped loop with the stomach, in the bend of which an important gland called the *pancreas* lies. This portion is called the *duodenum*. The upper two-fifths of the small intestine is called the jejunum, and the lower three-fifths ileum; but there is no demarcation between them, and the names are merely used to specify different parts of the length of the small intestine.

The small intestine is attached to the abdominal wall at the back by a strong sheet of ligament, covered on both its surfaces by peritoneal membrane, and called *the mesentery*. This mesentery is a strong, but thin and transparent, membrane,

which is attached by one border to the abdominal wall, down the mid line behind, and broadens out in a fan-shaped fashion to be attached to the whole length of the small intestine along its opposite border in front. It carries, between its folds, the vessels conveying the blood to and from the intestine, as well as the lymphatic vessels which arise in the walls of the intestine by minute lymphatic capillaries, and unite to form large lymphatic vessels in the mesentery.[1] The arteries run out like rays in a divergent fashion along the mesentery towards the intestine, and on nearing it join together and form arches, from which smaller branches pass inwards to feed the intestinal wall with blood. The returning veins follow the course of the arteries, and unite to form large veins which lie alongside the arteries. At its lower end the small intestine opens into the large intestine by an orifice which is closed by a valve (*ileo-cæcal valve*), formed by two folds arising from the inner part of the wall. This valve permits the intestinal contents to pass readily from the small to the large intestine, but bars all motion in the opposite direction. The entrance of the small into the large intestine is not placed quite at the beginning of the large intestine, but at one side near the beginning. That is to say, the small and large intestine are not joined up end to end, but the small opens into the large intestine laterally at a small distance from the end of the large intestine. The large intestine has hence a blind end or sac, which is termed the *cæcum*, and this is further prolonged into a small finger-like projection of much smaller bore, called the *vermiform appendix*. The length and capacity of the cæcum vary greatly in different animals; in the herbivora (for example, in the rabbit) it is very capacious, while in the carnivora (such as the cat and dog) it is rudimentary. It is also very small in man.

The *small intestine* lies in coils in the abdominal cavity below the liver and stomach. It occupies the greater part of the space, and is surrounded by the large intestine, which it joins in the lower part of the abdomen on the right side (see

[1] These mesenteric lymphatics are often termed *lacteals*, because they contain a milky white emulsion of fat when fat absorption is going on (see p. 156).

Fig. 55). The *large intestine*, or *colon*, has in man an average length of five to six feet. It passes upwards on the right side of the abdomen as the *ascending colon.* It then arches over to the left in a horizontal portion known as the *transverse colon*, which is seen in front (see Fig. 55) after removal of the great omentum, lying between the stomach and the folds of the small intestine. It next bends backward and downward, and passes down posteriorly to the small intestine as the *descending colon* on the left side of the abdominal cavity. The descending colon bends towards the middle line in the lower and posterior part of the abdominal cavity, and this bent portion is termed the *sigmoid flexure.* Finally, the sigmoid flexure leads to a straight tube with strongly developed muscular walls called the *rectum*, which ends in the external opening of the intestine known as the *anus.*

The large intestine is fixed in position by folds of peritoneum which surround it. The transverse colon is less closely fixed in this fashion than the other parts, being loosely attached to the abdominal wall at the back by a long fold of peritoneum (*the transverse meso-colon*). On the other hand, the peritoneum does not usually completely encircle the ascending or descending colon, but passes over them in a single sheet, which touches the intestine only for about two-thirds of its circumference, and is then reflected on to the abdominal wall, so firmly fixing the intestine in position.

The *spleen* cannot be seen from the front unless by displacing the stomach, as it is deeply placed behind and to the *left* side of that organ *in the left upper part of the abdominal cavity.*

The spleen is an elongated dark red coloured body filled with blood, which enters it along one side (which is concave and lies against the stomach) by a number of fairly large-sized arteries. These arteries subdivide within the substance of the spleen and finally give rise to a meshwork of capillaries which open out into spaces or sinuses in the tissue of the organ without any definite lining or wall. The blood is collected up again from these sinuses by capillaries leading to small veins which unite to form the splenic veins, and these issue from the spleen alongside the arteries. The function of the spleen is not clearly known. It is not essential to life, for animals continue to live in good health after it has been completely removed. It has the property of rhythmically contracting at intervals of about once a minute. These contractions are brought about

by strands of involuntary muscle fibre which pass inward along septa of connective tissue called *trabeculæ*. The trabeculæ arise from the outer sheath of the organ and pass inward, forming a framework from which lesser strands of connective tissue arise so as to make a network. The cells of the spleen are contained in this network as well as the capillaries and sinuses above mentioned. It is supposed that the spleen possesses the power of *destroying the effete or worn-out red corpuscles of the blood* (see p. 121), and some observers claim to have observed microscopically such a process of destruction going on in the spleen cells; still, the evidence on this point is not very convincing. The anterior surface of the spleen at which the blood-vessels enter and leave is concave, and attached to the stomach by the *gastro-splenic omentum*, a strong ligamentous band, coated over like everything else in the abdominal cavity by a reflexion of the peritoneal lining. The outer or posterior surface of the spleen is convex and unattached, it touches the diaphragm by its upper border, and lies obliquely against the posterior abdominal wall. The upper end is placed close to the left suprarenal body (*vide infra*) near the spine, and from this point the organ lies outward and downwards, following the course of the diaphragm for about halfway round the side.

The *kidneys* are two oval or bean-shaped bodies of a deep red colour, each about four inches long, two and a half inches in breadth, and rather more than an inch thick, which lie at the back of the abdomen on each side of the mid-line, opposite the last dorsal and upper two or three lumbar vertebræ. Their position is slightly oblique, the upper end being nearer to the spine than the lower, and the left is placed slightly higher than the right kidney. The external position opposite to which the kidneys lie is immediately beneath the last rib at the back, just on each side of the vertebral column. The kidneys are embedded in a mass of fat, and lie *behind the peritoneal lining* of the abdominal cavity, which is reflected over them in front as they bulge out into the abdominal cavity. The blood-vessels enter at the inner border where there is a depression in the surface called the *hilum*; here also the duct, or *ureter*, which conveys away the excreted urine, leaves the kidney. The ureters are two long slender tubes, one on each side, which leave the kidneys and pass to the bladder, into which they continuously pour the urine as it is secreted by the kidneys. They pass through the bladder wall very obliquely, and this produces a valve-like effect. For when the pressure is from the ureter to the bladder, the ureters remain open; but

when the pressure inside the bladder is increased, as is the case when it is being emptied, the increased pressure forces against each other the layers of the bladder wall, and so the mouths of the ureters, where these pass through obliquely, are closed, and no passage of urine from the bladder up the ureters can take place.

The *urinary bladder* is a distensible bag which serves to collect the urine between the periods of its discharge from the body. It lies in the mid-line at the lower or pelvic part of the abdomen, beneath the arch formed by the pubic bones, but may when distended appear above them. When distended it has a rounded or egg-shaped form, the broader end being towards the base, or fundus, which rests against the rectum behind. There are three openings to the bladder, of which two, those of the ureters, have already been described; these enter posteriorly at the upper part of the base on each side. The other opening is the *urethra*, by which the urine leaves the bladder.

The *urethra* is a tube with muscular walls, which leaves the bladder at its lower part or neck. It is kept closed, except when urine is being discharged from the bladder by a muscular ring or sphincter placed where it leaves the bladder.

The *suprarenal bodies* are two small yellow coloured glands situated one immediately above each kidney and close to the middle line. These bodies, though inconspicuous in size, are of vital importance in the body, for it is impossible to remove them without causing death. They are glandular in structure, and although they possess no ducts, it is probable that the cells secrete material which is poured directly into the blood-stream. A diseased condition of these bodies is associated with a peculiar and fatal malady (Addison's disease), which is, however, comparatively rare. A characteristic sign of this disease is a remarkable bronzing of the skin in patches; this is accompanied by muscular weakness, and a fall of the pressure of the blood in the arteries. It has recently been discovered that extracts of these glands in water, when injected into the veins of other animals, possess the property of greatly raising the pressure of the blood in the arteries, by constricting the

small arterioles all over the body, and hence preventing so rapid an escape of the blood through these, as it is pumped into the arteries from the heart. It has hence been suggested that the suprarenal bodies furnish to the blood an *internal secretion* which is essential for the maintenance of the tonicity of the muscle fibres surrounding the arterioles.

Another important ductless gland which may be conveniently mentioned here, although it is not contained in the abdomen, is the *thyroid gland*, which is situated in the neck, on each side of the trachea, near the thyroid cartilage. Complete removal of this gland in man, in cases where it has been diseased, has been found to cause death, and a similar result has been obtained in the case of certain classes of animals. The symptoms most closely resemble those seen in man, if monkeys are used for the experiment. In other animals, such as the dog, death occurs before certain of the symptoms have time to become manifest. The most remarkable symptom is a swollen condition of the connective tissue beneath the skin, producing a kind of artificial cretinism, which is known as *operative myxœdema*, this is accompanied by symptoms of a disturbance of the central nervous system in the form of tremors, spasms, and convulsions. These disturbances increase with the lapse of time, and finally lead to death. The condition is prevented or palliated by grafting of fresh thyroid tissue under the skin, or by feeding with fresh thyroid glands obtained from other animals. Much service has been done, by the knowledge thus acquired, in practical medicine by feeding patients similarly affected on the fresh glands of the sheep and other animals.

The good effects obtained by grafting the thyroid and by thyroid feeding, show that the thyroid secretes some substance which has a beneficial action in the body, and negative the theory[1] which has been proposed that the purpose of the thyroid and similar glands is to remove from the blood certain noxious substances which tend to accumulate therein.

[1] This theory is termed the *auto-intoxication* theory, in contradistinction to the other, which is known as the theory of *internal secretion*.

CHAPTER V.

THE CIRCULATORY SYSTEM.

THE circulation of the blood, carrying nutriment to all the tissues of the body and removing their waste products, is maintained by means of the heart and the system of tubes connected with it known as the blood-vessels.

Those vessels which carry the blood away from the heart are called *arteries*, and those which carry it back to the heart are called *veins*. Between these two systems of vessels there is communication in the tissues by an immense number of minute vessels, called *capillaries*, which have exceedingly thin walls. It is here, in the capillaries, that the real work of the blood is done; through the delicate walls of the capillaries, free interchange of nutrient materials and waste products takes place; while the larger vessels (arteries and veins) have thick impermeable walls, and merely serve the purpose of conveying and distributing the blood to the capillaries. The entire blood-vascular system, consisting of heart, arteries, capillaries, and veins, is completely lined internally by an exceedingly thin layer of flat pavement cells, which touch each other, and dovetail into each other by their thin edges. These flat cells are elongated in form, and each possesses a nucleus (see Figs. 56 and 59). In the case of the capillaries, they form the entire thickness of the wall, and hence there is free diffusion of substances in solution between the lymph (bathing the tissue and its cells) outside the capillary, and the blood inside the capillary. Also, at the cell junctions there are minute apertures through which the white cells (leucocytes) present in the blood can pass from the capillary into the lymph spaces without. The capillaries branch and anastomose freely with one another,

and unite at their ends to form *arterioles* and *venules*, the arterioles being next the arteries, and the venules next the

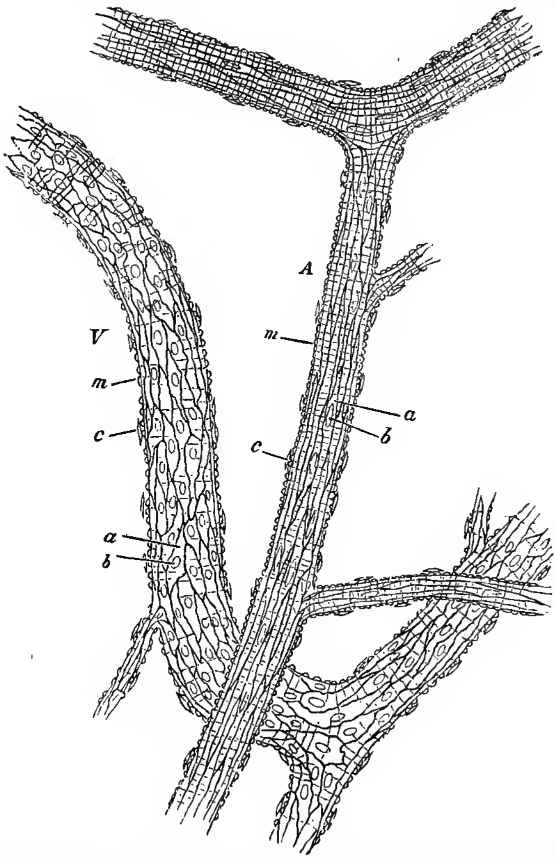


FIG. 56.—A small artery, *A*, and vein, *V*, from the subcutaneous connective tissue of the rat, treated with nitrate of silver. (175 diameters.) (E.A.S., Quain's "Anatomy.")
a, *a*, endothelial cells with *b*, *b*, their nuclei; *m*, *m*, transverse markings due to staining of substance between the muscular fibre cells; *c*, *c*, nuclei of connective-tissue corpuscles attached to exterior of vessel.

veins. In these small arteries and veins there are disposed outside the epitheloid coat (*endothelium*) layers of involuntary muscle fibres, which are arranged in a circular and slightly

spiral fashion around the tiny vessel. These are found at the places nearer the capillary as isolated cells and incomplete layers; but as the distance from the capillary increases, there is first formed a complete layer of the involuntary muscle fibres, and at points still more remote the muscle cells are several layers thick.[1] At the same time, a fine layer of elastic fibres forming an elastic membrane is found between the inner lining of pavement cells and the layers of muscle fibres. The muscular coat is much thicker in the small arteries than in the small veins, and the elastic coat outside the endothelium is also much more strongly developed. As the arteries and veins increase in bore their walls also increase in thickness, and

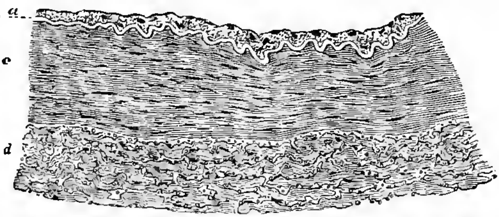


FIG. 57.—Transverse section of part of the wall of the posterior tibial artery. (75 diameters.) (E.A.S., Quain's "Anatomy.")

a, epithelial and subepithelial layers of inner coat; *b*, elastic layer (fenestrated membrane) of inner coat, appearing as a bright line in section; *c*, muscular layer (middle coat); *d*, outer coat, consisting of connective-tissue bundles. In the interstices of the bundles are some connective-tissue nuclei, and, especially near the muscular coat, a number of elastic fibres cut across.

there appears in addition an external coat (*areolar coat* or *tunica adventitia*) composed of connective-tissue fibres. Many of these fibres are elastic; especially in the arteries which require more elastic distensibility than the veins. It is this external coat which gives their great strength to the large vessels, and especially to the arteries in which it is well developed. In the very largest arteries, such as the aorta and its primary branches, the middle or muscular coat and the outer coat become to a certain extent blended so that there is an admixture of elastic and muscular fibres.

In a typical medium-sized artery (see Fig. 57) the wall is

[1] The purpose of this muscular coat in the arterioles, and the manner in which it regulates the supply of blood to a given part, have already been described (see pp. 57, 60).

usually described as consisting of three coats, namely, an *inner* or *elastic* coat (*tunica intima*), consisting of the innermost pavement layer or endothelium and the elastic membrane; a *middle*

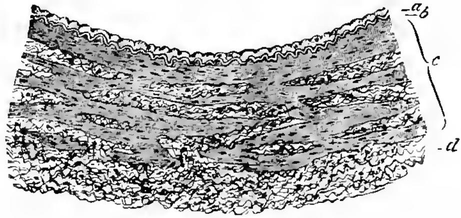


FIG. 58.—Transverse section of part of the wall of one of the posterior tibial veins (man). (E.A.S., Quain's "Anatomy.")

a, epithelial and subepithelial layers of inner coat; *b*, elastic layers of inner coat; *c*, middle coat consisting of irregular layers of muscular tissue, alternating with connective tissue, and passing somewhat gradually into the outer connective tissue and elastic coat, *d*.

or *muscular* coat (*tunica media*), consisting of concentric non-striated muscle cells; and an *external* or *areolar* coat (*tunica extima* or *tunica adventitia*). The larger veins very closely resemble the arteries in structure, but their walls are much thinner, as they contain both less muscular and less elastic tissue (compare Figs. 57, 58).

On account of the large amount of elastic tissue which the arterial walls contain, they are capable of being distended when the pressure within them is increased, and of regaining their original bore when this pressure decreases again. The veins, on the other hand, are not so distensible by pressure. The united cross section of the large veins is about double that of the correspondingly large arteries, and they are never quite distended by blood under normal conditions.

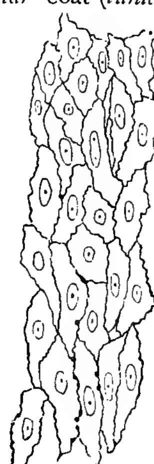


FIG. 59.—Epithelial layer lining the posterior tibial artery. (250 diameters.) (E.A.S., Quain's "Anatomy.")

The heart is a double force-pump containing four chambers, two of which are placed on the right side, and together constitute what is often termed the *right heart*, and two on the left side, forming the *left heart*. This duplicate arrangement is necessary because

the entire course of the circulation forms two nearly complete circuits, as shown in the accompanying diagram (Fig. 61), and a given quantity of blood in a complete round comes twice to the heart.

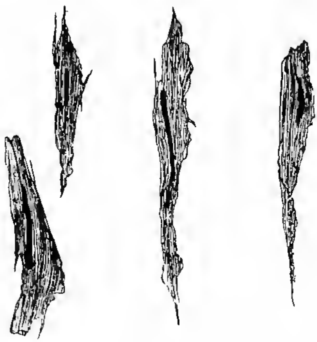


Fig. 60.—Muscular fibre cells from superior thyroid artery. (340 diameters.) (E.A.S., Quain's "Anatomy.")

The upper chamber on each side is thin walled, and incapable of exerting or withstanding any great amount of pressure. It is called the *auricle*, and its purpose is, by a preliminary contraction,[1] to completely fill the lower chamber or ventricle before this contracts and drives the blood into the large artery leading away from it.

The *ventricle* on each side is a chamber with very thick muscular walls capable of exerting considerable pressure, when it contracts, upon the blood contained within it. There is a valve arranged between each ventricle and its corresponding auricle which opens towards the ventricle, and another between each ventricle and the large artery which issues from it, opening towards the artery (see Figs. 65, 66). On account of these valves *the blood can only move in one direction* when the ventricular wall contracts upon it, namely, *from the ventricle into the artery.*

There is no valve placed between each auricle and the great veins which enter it, in order to prevent the blood from flowing, when the auricle contracts, from the auricle into these great veins, instead of into the ventricle, because there is less resistance in the direction of the ventricle than in the direction of the veins, and the auricle never gets up sufficient pressure under normal conditions to force the blood back into the veins instead of into the ventricle. When the auricle contracts, the blood is not under pressure in the ventricle, and the effect of

[1] The contraction of either auricle or ventricle is known as its *systole*, and its relaxed or uncontracted condition as its *diastole*.

the auricular contraction is merely to slightly distend the ventricle and to float the *auriculo-ventricular* valve[1] (*i.e.* valve

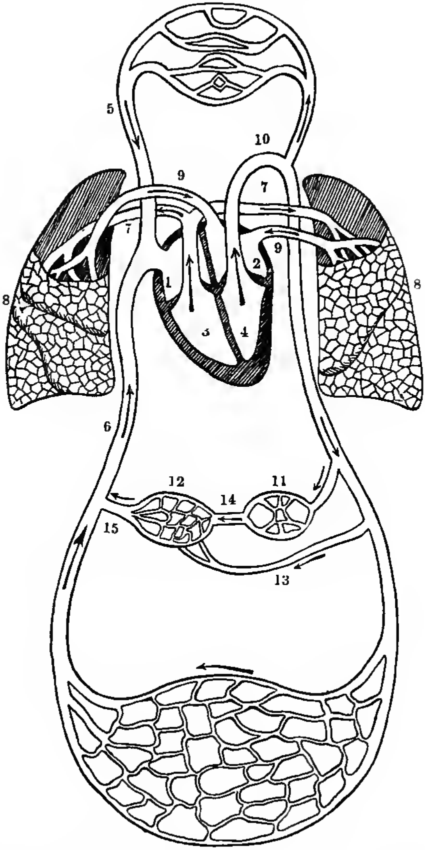


FIG. 61.—Schematic diagram to illustrate the course of the circulation. (Furneaux's "Physiology.")

1, right auricle; 2, left auricle; 3, right ventricle; 4, left ventricle; 5, vena cava superior; 6, vena cava inferior; 7, pulmonary arteries; 8, lungs; 9, pulmonary veins; 10, aorta; 11, vessels of alimentary canal; 12, vessels of liver; 13, hepatic artery; 14, portal vein; 15, hepatic vein.

[1] The auriculo-ventricular valve on the left side is called the *mitral valve*, that on the right the *tircuspid valve*. The valves placed on the aorta and pulmonary arteries, as they respectively issue from the left and right ventricles, are called the aortic and pulmonary *semilunar valves*.

between auricle and ventricle) up into a closed position. The main work at each heart-beat thus comes on the thick-walled ventricles which have to force the blood into the arteries, where there exists a considerable pressure (*arterial pressure*), the cause and need of which will be presently considered.

Beginning at the point where the blood is poured into the right auricle by the superior and inferior *venæ cavæ*, the course of a complete circulation may be indicated as follows (see Fig. 61). The blood flows into the right auricle, and from this, during the pause before a heart-beat, freely into the right ventricle; further, an additional quantity is helped in before the contraction (systole) of the right ventricle by the preceding contraction (systole) of the right auricle. From the right ventricle the blood is pumped by the systole into the pulmonary artery, which branches and carries it to the lungs. Here the blood is spread out in a thin layer by a vast meshwork of capillaries, and is only separated from the air filling the air spaces (*air cells*) of the lung by the thin walls of these capillaries. While passing through these capillaries gaseous interchange takes place between blood and air, in consequence of which the blood loses carbon dioxide formed in the various tissues by oxidation processes going on there, and takes up a charge of oxygen for use in the tissues in the next round. In consequence of these changes in the gases it holds, the blood changes in colour from dark purple to bright scarlet, or, as it is termed, is changed from *venous* to *arterial* blood.[1] The blood is gathered up from the lung capillaries by veins, which unite with one another to form larger venous trunks, and leave the lungs as the pulmonary veins, which carry the arterialized blood back to the heart. Here it enters the *left* auricle, and passes, in a similar manner to that on the right side, into the *left* ventricle. By the systole of the left auricle, the left ventricle is completely filled; then this chamber passes into systole, and the blood is driven under pressure into the aorta. The aorta and its various branches distribute the blood to all parts of the body, some passes to this organ and

[1] The nature and mode of these changes in the blood will be more fully discussed elsewhere (see pp. 173, *et seq.*).

some to that, and after circulating through the capillaries of the part, each portion is collected up by veins, which gradually unite and increase in size. The larger veins pour their contents into the great venous trunks, the superior and inferior *venæ cavæ*, and these empty the blood into the right auricle, *so completing the circuit.*

The circuit between right auricle and left ventricle *viâ* the lungs is termed *the lesser or pulmonary circulation*, and that from left ventricle back to right auricle is known as *the greater or systemic circulation.* These pumping operations by the two force-pumps on the right and left side of the heart *go on simultaneously.* First, both auricles contract at the same instant (*auricular systole*), then, immediately after, both ventricles contract together (*ventricular systole*), and there follows a pause (*diastolic pause*), during which all four chambers are relaxed. This whole cycle of events occupies about $\frac{8}{10}$ to $\frac{9}{10}$ of a second, of which about $\frac{1}{10}$ of a second is taken by the auricular systole, $\frac{3}{10}$ of a second by the ventricular systole, and the remainder of $\frac{4}{10}$ to $\frac{5}{10}$ of a second by the diastolic pause.[1]

Certain sounds, known as the *heart sounds*, are heard when the ear is applied to the chest of another person over the region of the heart, or may be heard in one's self when lying quietly on one side in bed. Two sounds are heard, one immediately after the other, followed by a pause. The *first* sound is lower in pitch and more prolonged than the *second*, which is short and sharp like that produced by softly plucking a piece of linen cloth, such as a pocket-handkerchief.

The first sound is produced partially by the contraction of the muscular substance of the ventricular walls, and partially by the rush of the blood from the ventricles into the arteries. The second sound is made by the closure of the valves

[1] The rate of the heart-beat varies under different conditions from time to time, being increased by exercise, excitement, or fever, and lessened by repose, assuming the recumbent position, or sleeping. It also varies with age, being about 120 to 150 per minute in the new-born infant, 80 to 90 in the child, 70 to 80 in the adult, and 50 to 60 in old age. It must be understood, however, that the individual variations are very considerable.

guarding the entrances of the aorta and pulmonary arteries. For the pressure in the ventricles when their contraction is over falls below that in the arteries, and these valves then fill out and close together to keep the blood from rushing back from the arteries into the ventricles again. In consequence, the first heart sound occurs during the ventricular systole, and the second at the commencement of the diastolic pause, just as the ventricles relax.

These sounds are of great importance in practical medicine, because they become altered in many diseased conditions of the heart, and the character of the alteration gives a clue to the nature of the disease. The physician listens to them by means of an instrument called a stethoscope, which is in principle a hollow tube, or double tube, serving to convey the sounds from a small area of the chest wall to the observer's ear.

Since the right and left ventricle beat at exactly the same rate, and all the fluid sent from the right ventricle to the lungs must be afterwards sent from the left ventricle round the system,[1] it follows that the volume of blood discharged at each systole from the right ventricle must be equal to that discharged from the left, and as the volume of the ventricle must become adapted to the volume which it discharges continually during life, it also follows that the *internal* volume of the two ventricles must be the same. It is difficult to determine this volume accurately, but it has been estimated at 4 to 5 ounces, or 100 to 120 cubic centimetres.[2]

Although the entire vascular system possesses the exceedingly smooth epitheloid lining above described, which has the effect of diminishing the resistance to the flow of the blood through it to a minimum, yet there is a considerable resistance to the flow, which is practically all due to the fine bore of the

[1] With the exception of a comparatively negligible quantity lost by evaporation in the lungs.

[2] That is, a little more than a medium-sized hen's egg; hence when the rate at which the heart beats is taken into account, the vast volume of blood sent through the heart per day is realized. To obtain the day's work of the heart this volume must be multiplied by the sum of the pressures at which it is driven into the aorta and pulmonary artery; this is equal to a pressure of about 8 feet of water, so that the amount of work done daily by the heart is very considerable.

capillaries and the smaller arteries and veins adjoining them. This form of resistance is what is known as fluid resistance. When a fluid flows along in a channel or tube, there is a certain amount of resistance to the flow due to the roughness of the inner wall in impeding the flow of the layers of fluid nearest to it, called the *skin resistance;* this is reduced to a minimum in a normal condition of the blood-vessels of the body by the smoothness of their internal coat. But, besides this, there is a friction, due to the movement of the layers of fluid on each other. Those portions of fluid in the central part of the bore of the tube move more rapidly than portions nearer the wall of the tube, thus there is a brushing of the fluid against itself, which impedes and delays its motion as a whole. The amount of this resistance varies with the *velocity* of the fluid, with its *viscosity*, or internal friction, and with the *bore* of the tube. As the bore decreases, the resistance becomes enormously increased, so that it requires a great pressure to drive fluid through very fine tubes with any considerable velocity. Now, the blood is a fluid with considerable viscosity, and the capillaries through which it has to be driven are exceedingly narrow, so that to accomplish the purpose the pressure in the arteries (*arterial blood-pressure*) must be maintained high.

This shows the necessity for the thick-walled muscular ventricles for the strong auriculo-ventricular, aortic, and pulmonary valves, and for the strong-walled elastic arteries.

The resistance in the pulmonary circuit is not nearly so great as that in the systemic circuit, and *hence the blood-pressure in the pulmonary artery is only about one-third of that in the aorta.* The walls of the pulmonary arteries are hence not nearly so thick as those of the aorta and its principal branches, and in the case of the ventricles themselves the left has very much thicker walls than the right, so that although the internal volume of the two ventricles is the same as pointed out above, the *external* volume of the left ventricle greatly exceeds that of the right.

The blood pressure in the arteries increases somewhat at each stroke of the ventricles, and falls back between the strokes;

it probably equals on the average *in the aorta in man the pressure of a column of mercury* 120–140 *millimetres high*,[1] which is nearly equivalent to *a column of water about* 6 *feet high*.

The pressure falls in each part of the circulatory system proportionately to the resistance passed. Since there is practically no resistance in the larger arteries, there is very little fall below that of the aorta (or pulmonary artery respectively) until the arterioles are reached. The amount of pressure (or *head*, as it is called) lost in the arterioles is very variable, according to whether the muscular walls of these are constricted or relaxed, but is always much greater than that lost in the larger arteries. In the capillaries a still greater resistance is encountered, and a great fall in pressure results; so that when the veins are reached nearly all the arterial pressure has been dissipated in overcoming resistance. The veins are wide tubes, like the arteries, and very little pressure is required to send the blood along them back to the heart; so that, although there is a slow fall, the gradient is very slight. Finally, when the auricles are again reached by the returning blood, all that pressure under which it was sent forth on its round by the ventricles has become lost. In fact, each time we draw our breath the lungs are filled, as has been previously said, by the suction on them of the enlarged thorax, and this suction comes to bear, not only on the lungs, but on all distensible structures within the thorax; so that there is a suction on the large veins within the thorax as also upon the auricles themselves.[2] Hence, in inspiration, the pressure in the large veins may not only fall to zero, but become negative, and as this suction is transmitted to the large veins immediately outside the thorax, such as the *jugular* in the neck, if such a vein be inadvertently cut, air may enter during inspiration, on account of this negative pressure, and produce fatal results when it reaches the heart.

[1] For methods of measuring blood pressure, the student must consult larger text-books.

[2] Another effect of this suction is to cause a greater flow of blood towards the thorax, and hence towards the heart, during inspiration. This increased amount of blood is pumped round by the heart; so that there is a small *rise* of blood pressure *during inspiration*, and a small *fall during expiration*.

The arteries, as has been pointed out above, are tubes with elastic[1] walls capable of being distended under pressure as the blood is pumped into them from the ventricles, and of recovering their former dimensions as it escapes into the capillaries. The use of this property is obvious, for if the arteries were rigid tubes under pressure, each quantity of fluid shot into them would produce a spurt passing all through the vascular system. There would be no steady stream passing through the capillaries to feed the tissues, but instead a useless onward spurt at each stroke, and between the strokes no forward flow. In fact, perfectly rigid tubes to replace the arteries it is almost impossible to conceive in action; for the capillaries are so narrow that they would present an enormous resistance to the flow of blood through them with such a sudden large velocity, and so the arteries would burst, or the heart stop dead, incapable of expelling its contents in face of such a resistance. The distensibility of the arteries plays in the vascular mechanism exactly the same part as the air-chamber of a pumping or fire-engine, or as the indiarubber cover of a chemical bellows. At each heart-beat the quantity of blood discharged from the ventricle somewhat further distends the large arteries and increases the pressure slightly within them. Then, after the blood ceases to flow in (during the diastolic pause), the elastic walls of the artery continue to press on the blood and drive it in a steady stream onward into the capillaries. It is this action of the arterial walls which is responsible for the difference in character of the flow from a cut artery and that from a cut vein respectively. When an artery is cut there is a rapid flow in jerks *from the end nearer the heart;* when a vein is cut there is a slower, oozing, and constant flow *from the end farther from the heart and nearer to the capillaries.* The difference in the ends from which the blood flows is caused by the direction of the blood-stream; the more rapid flow from the artery is due to the higher pressure under which the blood is within it; and the spurting flow from the artery is due to the heart-beats

[1] The word "elastic" is here used in the popular sense to mean distensible by pressure and capable of recovery afterwards, and not in the technical sense used by physicists.

rhythmically increasing the pressure; while the constant flow from the vein is the result of the uniform pressure established by the interposed resistance of the capillaries by means of which, combined with the elastic pressure of the distended arteries, the stream is made constant.

It may be gathered from the foregoing account that two factors are necessary to convert the *pulsatile* flow of the arteries into the steady flow of the veins—viz. first, the elastic arterial wall distended under pressure; and, secondly, the peripheral resistance of the small channels (arterioles and capillaries) interposed between the arteries and veins. When this peripheral resistance is much diminished, as, for example, when the muscular walls of the arterioles are much relaxed, the blood can pass too easily through the arterioles and capillaries, and appreciably more passes when the pressure is increased at a ventricular systole, than during ventricular diastole: hence the flow in the veins beyond these distended arterioles becomes faintly pulsatile or jerky.

Another important outward physical sign of the circulation, namely *the pulse*, is due also to the elasticity of the arterial walls. When fluid is forced at any point into an elastic tube distended by internal pressure, a wave is set up which travels away from this point with a definite velocity depending upon the elasticity of the wall and the pressure upon it. In this way an elastic wave is set up in the aorta and its branches as each quantity of blood is discharged from the left ventricle into its upper end. This wave is known as the *pulse wave*, and occasions the pulse felt when an artery at any part of the body is compressed by the finger. The pulse has the same frequency as the heart-beat, and so is a signal of the rate and regularity with which the heart is working. By its character it also gives an indication of the amount of pressure within the artery. It must not be supposed that the pulse wave is directly due to the motion of the blood along the artery, any more than the waves of the sea mean a motion of the water in the direction of the waves. When a fresh quantity of blood is thrown into the beginning of the aorta there is a distension of this portion of the aorta, and afterwards

a back-swing, the distension is propagated along the aorta and its branches, and it is this propagated wave which is the pulse. If the pulse movements be magnified, as can be done by an instrument called a *sphygmograph* (consisting essentially of a pad which presses on the artery and moves a lever, the longer end of which writes on a smoked paper surface moved past it by clockwork), it is seen that the pulse is not a simple wave, but has several secondary waves upon it (see Fig. 62). These

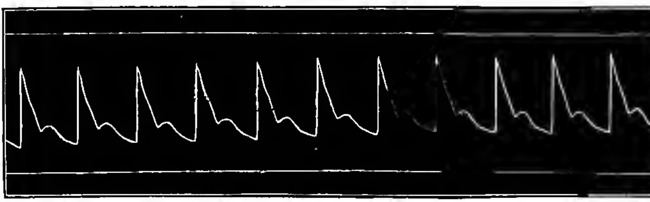


FIG. 62.—Sphygmographic tracing.

The tracing, which is to be read from left to right, is a record of the pulsations of the radial artery in man. The first strong upstroke shows the primary or percussion wave. The notch is the "dicrotic notch," and the wave following it is the "dicrotic wave."

secondary waves are due to elastic after-vibrations of the artery, and one, called the *dicrotic wave*, is accentuated by a smaller wave caused by the closure of the semilunar valves as the pressure of the blood in the aorta shuts them after the ventricle has commenced to relax. This dicrotic wave becomes magnified when the pressure in the arteries is low.

The rate at which the pulse wave travels is variable, being increased either by greater rigidity of the arterial walls or by increased arterial pressure; it is approximately 3 to 4 metres (*i.e.* 10 to 13 feet) per second.

The real *velocity of the blood-stream* along the arteries is many times less than this, amounting to only 30 centimetres (about 1 foot) per second in the aorta.

There is a definite *relationship between the velocities of the blood in the various parts* (arteries, capillaries, and veins) *of the vascular system*, which *is determined by one thing only*, viz. *the relative total cross-section*[1] *of the vascular system at the*

[1] A cross-section is the area made by a cut at right angles to the bore of the tube (artery, capillary, or vein).

given point. Each time that an artery branches on its way to the supply of a tissue, although the branches become smaller their *united* cross-section becomes greater. The united cross-section of the capillaries is many times greater than that of the great arteries or veins. If the cross-section of the aorta be taken as unity, then the united cross-section of the capillaries is approximately 500, and the united cross-section of the *venæ cavæ* is about 2; it follows that the average velocity of the blood-flow in the capillaries is 500 times slower than in the aorta, and in the *venæ cavæ* is about half as fast. For the blood must pass in turn, in making the complete circuit, through the entire vascular system. A quantity of blood flowing in a given time along the aorta must flow in the same time exactly through the united capillaries, and afterwards through the *venæ cavæ.* Now, the velocity of flow is evidently obtained by dividing the quantity of blood flowing in the unit of time by the cross-section of the channel or channels through which it flows. If the channel be of twice the area the blood must only flow at half the rate for the same quantity to flow in the same time. *Hence, as the same blood flows all round the circuit, the velocity at any part is inversely proportional to the total cross-section at that part.*

The velocity in the aorta being about 30 centimetres (about 1 foot) per second, that in the capillaries will roughly average on the above basis something over half a millimetre ($\frac{1}{40}$ of an inch) per second, and that in the great systemic veins about 15 centimetres (6 inches) per second.

It is often erroneously stated that the resistance in the minute capillaries is a cause of the slow flow of the blood in these vessels as compared with that in the arteries, but this is a fallacy; the *comparative* cross-section is the only factor in determining the *relative* velocities. It is indeed true that a *diminution of the resistance* in the capillaries, or rather in the small arterioles which lead to them, *will increase the flow* through these capillaries, but it will proportionately increase the velocity of flow in the arteries and veins, if the diminution in capillary resistance be general all over the body, and hence the relative velocity will remain unchanged. In this manner, any

general change in velocity at any part of the circuit must tell backward and forward on the velocity in all other parts of the circuit, and the *average* velocity in arteries, veins, and capillaries must remain purely determined by the relative total cross-section at these various parts.

The *local* velocity through the capillaries of a given area—say of the capillaries of any particular organ in the body—is, however, much more important than the average capillary velocity, and this can be altered very widely, without much altering the velocity in the arteries or veins, by means of variations in the calibre of the arterioles supplying the part. These variations are brought about by nerve action through nerve fibres supplied to the involuntary muscle coat of these arterioles—*the vaso-motor fibres*. By this means the distribution of the blood-stream to the different organs is regulated ; almost shut off when the demand is small, through the organ becoming dormant, and turned on in full when the organ again passes into a state of activity. The vaso-motor nerve fibres, and the involuntary muscle coat of the arterioles on which they act, are thus to the circulation of the blood what the distributing taps are to a water-supply, allowing the stream to flow where there is work for it to do, and shutting it off where it is not required. The only difference is that, in the body, the taps are never completely shut down, they are only more or less widely opened. The reason for this is, that living tissue cannot go on for a long period without a supply of oxygen (which is carried to it by the blood-stream). Even in a resting condition a certain amount of activity goes on, accompanied by oxidation and need for respiration. But when the cells become active, the amount of change becomes largely increased, and the blood-supply must also be increased to cope with the larger demand.

In certain veins, particularly in those of the limbs, the action of the heart is assisted by valves placed in the walls at intervals. These *venous valves* are very simple structures, consisting of two pouch-like invaginations of the inner coat of the vein placed opposite each other (see Fig. 63). They open towards the heart, and allow of the passage of the blood in that direction, but close and prevent any flow in the opposite

direction. The use of these valves is in determining the direction of flow when a vein is compressed by muscular action in moving the part. Were there no valves, the contents of the vein on compression would move in both directions to and from the heart, so as to empty the compressed portion, for the venous pressure (5–15 millimetres of mercury) is too small to prevent this action. But the valves have the effect of causing the vein to empty its contents towards the heart only, and so assist the heart in its work. This action is best seen in the long veins of the leg, which are plentifully supplied with valves. If a person remain perfectly at rest for some time in an upright position, the veins at the lower part of the leg, about the ankle, become considerably swollen, because the venous pressure is thus greatly increased, and the veins become rounded and distended by the increased pressure. The pressure in the veins must, under such conditions, be equal to the hydrostatic pressure of a column of blood reaching up to the heart before the blood can move upward to the heart along these veins, and this is a considerable pressure.[1] But let the person now make a few muscular movements of the legs, such as by walking about vigorously, and the distension becomes greatly diminished, because the valves now come into action, and the blood is pumped upwards by their action, as the skin compresses them on account of the movement of the underlying muscles.

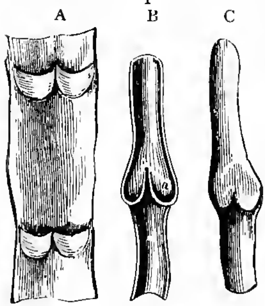


FIG. 63.—Diagram showing the valves of veins. (Quain's "Anatomy.")
A, part of a vein laid open, with two pairs of valves; B, longitudinal section of a vein, showing the valves closed; C, portion of a distended vein, exhibiting a swelling at a pair of valves.

The action of the venous valves may be tested by compressing with the finger a long superficial vein of the arm or

[1] It is probably impossible to stand so still that there is no action at all of these valves. It may also be well to point out that the heart has not to do work against the hydrostatic venous pressure above mentioned, since it is balanced by an equal column in the arteries, and that the chief evil effect is the distension of the veins, which is relieved by the action of the valves when there is sufficient muscular action

leg.[1] If the vein be stroked towards the heart, the blood runs easily in front of the finger and leaves the vein almost empty behind it; but, if it be stroked in the opposite direction, the vein swells up and becomes knotted at points where the valves are situated.[2]

STRUCTURE OF THE HEART.

We may now consider more in detail the mechanism of the heart-pump, and the arrangement of its valves. The description can only be followed profitably if accompanied by a dissection of a heart. A sheep's heart can easily be procured from a butcher, and should be obtained with the attached vessels as long as possible, and uninjured by knife-cuts.

In the dead heart by far the greater part of the bulk is made up of the two ventricles. The auricles are two comparatively inconspicuous appendages of a deep purple colour placed above the ventricles. This is, in part, due to the fact that even the internal capacity of the auricles when distended with blood is somewhat less than that of the ventricles, and in part to the fact that the auricles have thin and the ventricles thick walls, so that the external volume of the ventricles is much greater than that of the auricles.

There is a deep transverse groove round the heart, the *auriculo-ventricular groove*, separating the auricles from the ventricles. Another somewhat **U**-shaped groove, called the *inter-ventricular groove*, separates the two ventricles; it contains blood-vessels and some fat, which serve to more clearly mark its position. This groove passes near, but not over, the apex of the heart, for the entire apex belongs to the left ventricle, which serves as a sign to identify it in the excised heart. Even before making any incision into the heart, the

[1] Some veins have no valves, for example, the *venæ cavæ*, the pulmonary veins, and the veins of the liver (portal and hepatic veins).

[2] This experiment can be best carried out on another person with prominent veins. Compress a long vein of the arm with one forefinger, and then with the other forefinger stroke it upwards towards the heart; the vein empties, and remains empty for a certain distance up, where a prominent valve appears. On releasing the vein, it fills from the peripheral end. If the experiment does not succeed with one vein try another.

thinner wall of the right ventricle, as compared with the left, may be appreciated by pressure with the fingers.

When the heart is in position in the body, the right side lies more anteriorly than the left; so that when seen from the front, two-thirds is formed by the right ventricle, and only the third on the left is left ventricle.

Each auricle is prolonged somewhat at one side into a process resembling the lobe of the ear, and hence termed the *auricular*[1] *appendage.* The main part of each auricle is termed the *atrium*, or *sinus venosus*, because the veins open into this part.

The great vessels entering the base of the heart should next be examined.

The aorta is distinguished by having the thickest wall, and by the fact that the little finger when inserted into it, can be passed into the left ventricle without first passing through the left auricle. The pulmonary artery has the next thickest wall, and the finger when passed through it passes directly into the right ventricle. The remaining vessels are veins; two enter the right auricle—these are the *superior* and *inferior venæ cavæ.* The veins entering the left auricle come from the lungs, and are termed the *pulmonary veins.* Their number is variable in different animals. In the sheep there are usually two; in man there are four, two from each lung.

The interior of the heart-chambers and the arrangement of the valves should next be studied, and it will be well in doing so to follow the course of the blood through the heart.[2]

To expose the inner surface of the right auricle, make a cut from the superior to the inferior *vena cava*, and another running nearly at right angles from the middle of this into the auricular appendix. The inner wall shows muscular ridges over the appendix and upon the right side of the atrium, while the rest of the wall is much smoother. On the inter-auricular septum, separating this chamber from the left auricle, an oval depression may be seen, called the *fossa ovalis* (see Fig. 64);

[1] The whole auricle gets its name from a fancied resemblance to the external ear.

[2] Before making the incisions above described, the student should, if provided with the necessary apparatus, perform the experiment described in practical exercises, to demonstrate the action of the valves.

this corresponds to a former opening between the two auricles which existed in the fœtus, and served an important purpose before the lungs came into use, in directing the blood into the left auricle directly, instead of *viâ* the lungs; it became closed later, as the lungs came into use after birth, by a fold of tissue, which originally served as a valve for it.

At this stage in the dissection, if the auricle be held open and the water be poured into it from a slight height, so as to pass into the ventricle, the action of the auriculo-ventricular valve may be demonstrated. As the water fills the ventricle, the flaps of the valve float up and close the opening. This resembles what happens during life, when the auricle contracts and forces its contents into the already almost full ventricle. The valve-flaps then float up, and their edges become opposed, so that all is ready for the ventricular systole, and there is no back-flow into the auricle at the beginning of the stroke.

Observe, further, that there are no valves at the openings of the *venæ cavæ* into the auricle. Such valves, as has already been stated, are unnecessary, because there is no *great* force exerted by the auricular contraction, which simply serves to completely fill the ventricle.[1]

Next open the right ventricle by making an incision with a knife into it parallel to the inter-ventricular groove, and following this round at some distance from the groove so as not to injure the *inter-ventricular septum*.[2] By means of this U-shaped incision a flap is made which can be turned outward from the apex, and so the interior of the ventricle be examined. Feel with your finger, from the inside of the ventricle, for the opening of the pulmonary artery into the ventricle, and make certain that you have found it by seeing that you come out at the external opening of the pulmonary artery which you have

[1] Back-flow into these veins is also prevented by the facts, that there is little resistance to the discharge into the ventricle, that there is already a current of blood towards the auricle in the veins, and that the veins assist the process by a slight contraction of their walls immediately preceding that of the auricle.

[2] This is the muscular septum separating the two ventricles. It is somewhat convex towards the right ventricle; so that the right ventricle is crescentic in cross section, while the left ventricle in cross section is oval or rounded.

previously identified as above described. Now, using your finger as a guide, continue the previous cut in the ventricle up towards the pulmonary artery, and cut through the lower portion of the wall of this, if possible between two of the three flaps of the semilunar valve which guards its orifice. Finally, cut away the lower part of the flap of ventricular wall already partially detached, so as to expose the interior of the ventricle more completely.

The inner surface of the ventricle is ridged by strong muscular bundles (the *columnæ carneæ*), some of which are attached to the wall of the ventricle all the way, others are free in the middle, but attached at both ends (*trabeculæ*), while others, again, are attached to the ventricular wall only at their base (*musculi papillares*). This last set (musculi papillares), which form two chief bundles, anterior and posterior, serve as contractile pillars for the attachment of strong fibrous cords (the *chordæ tendineæ*), which are fixed by their other ends to the edges and under-surfaces of the flaps of the tricuspid valve. The tricuspid valve (see Fig. 64) guards the passage from the right auricle to the right ventricle, and makes this opening impermeable when the ventricle contracts. It consists of three thin but strong fibrous flaps, roughly triangular in form, with their bases attached in a complete ring round the auriculo-ventricular orifice, and their apices towards the ventricle. To the edges of the flaps, and to their under-surfaces, the strong thin *chordæ tendineæ* above mentioned are attached, and hold the flaps in position so as to prevent them bulging into the auricle when the ventricle contracts and the blood presses upon their under surfaces.

The musculi papillares are a compensating arrangement. If the cords by which the flaps are held down were non-contractile, and ran straight from the valve to the ventricular wall, then the wall would move towards the valve as the ventricle contracted, the ends of the restraining cords would move with it, the flaps would be allowed to move too far up, and the valve become incompetent. This is prevented by the contractile musculi papillares, which shorten as the ventricle contracts, and so hold the valves in the proper position.

The wall of the ventricle near the mouth of the pulmonary artery is smooth, and conical in shape (*conus arteriosus*), narrow-

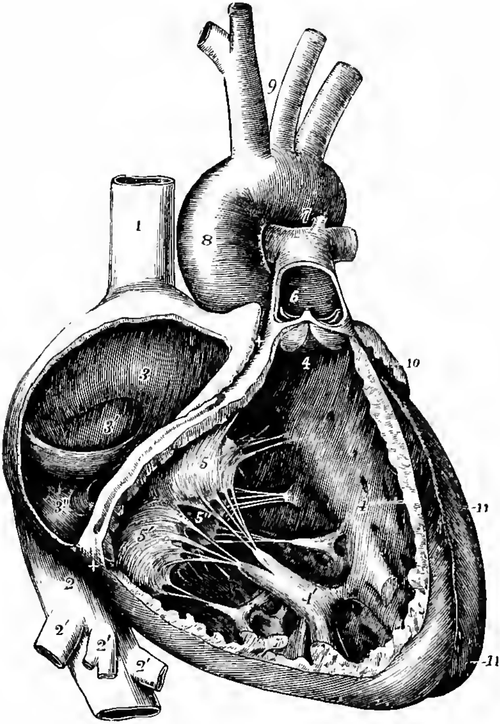


FIG. 64.—Interior of the right auricle and ventricle, exposed by removal of the greater part of their right and anterior walls. (Allen Thomson.) ½

1, superior vena cava; 2. inferior vena cava; 2', hepatic veins; 3, septum of the auricles; 3', fossa ovalis; the Eustachian valve is just below; 3", aperture of the coronary sinus with its valve; +, +, right auriculo-ventricular groove, a narrow portion of the adjacent walls of the auricle and ventricle having been preserved; 4, 4, on the septum, the cavity of the right ventricle; 4', large anterior papillary muscle; 5, infundibular, 5', right, and 5", posterior or septal segment of the tricuspid valve; 6, pulmonary artery, a part of the anterior wall of that vessel having been removed, and a narrow portion of it preserved at its commencement where the pulmonary valve is attached; 7, the aortic arch close to the cord of the ductus arteriosus; 8, ascending aorta covered at its commencement by the auricular appendix and pulmonary artery; 9, placed between the innominate and left common carotid arteries; 10, appendix of the left auricle; 11, 11, left ventricle.

ing towards the artery. The mouth of the artery is circular, and about an inch in diameter; it occupies the summit of the

FIG. 65.—The left auricle and ventricle opened and a part of the wall removed so as to show their interior. (Allen Thomson.) ½

The commencement of the pulmonary artery has been cut away, so as to show the aorta; the opening into the left ventricle has been carried a short distance into the aorta between two of the semilunar flaps; and part of the auricle with its appendix has been removed. 1, right pulmonary veins cut short; 1′, placed within the cavity of the auricle on the left side of the septum, on the part formed by the valve of the foramen ovale, of which the crescentric border is seen; 2′, a narrow portion of the wall of the auricle and ventricle preserved around the auriculo-ventricular orifice; 3, 3′, cut surface of the wall of the ventricle, seen to become very much thinner towards 3″, at the apex; 4, a small part of the wall of the left ventricle which has been preserved with the left papillary muscle attached to it; 5, 5, right papillary muscles; 5′, the left side of the septum ventriculorum; 6, the anterior or aortic segment, and 6′, the posterior or parietal segment of the mitral valve; 7, placed in the interior of the aorta near its commencement and above its valve; 7′, the exterior of the great aortic sinus; 8, the upper part of the conus arteriosus with the root of pulmonary artery and its valve; 8′, the separated portion of the pulmonary trunk remaining attached to the aorta by 9, the cord of the ductus arteriosus; 10, the arteries arising from the aortic arch.

ventricle, being situated slightly higher than the auriculo-ventricular opening, and is guarded by a valve with three pouch-like (semilunar) flaps (see Fig. 66), called the *pulmonary semilunar valve*, which opens towards the artery.

The construction on the left side of the heart is very similar to that on the right, except that everything is more strongly

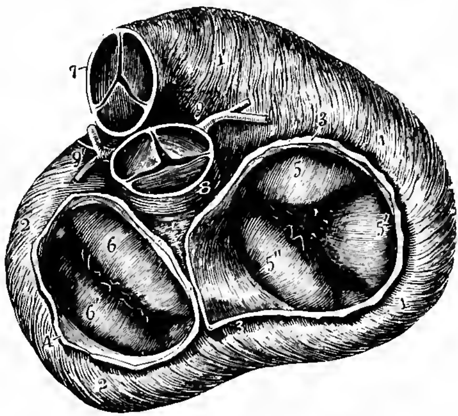


FIG. 66.—View of the base of the ventricular part of the heart, showing the relative position of the arterial and auriculo-ventricular orifices. (Allen Thomson.) $\frac{2}{3}$

The muscular fibres of the ventricles are exposed by the removal of the pericardium, fat, blood-vessels, etc.; the pulmonary artery and aorta and the auricles have been removed; the valves are in the closed condition. 1, 1, right ventricle; 1′, conus arteriosus; 2, 2, left venticle; 3, 3, the divided wall of the right auricle; 4, that of the left; 5, the infundibular; 5′, the right, and 5″, the septal segment of the tricuspid valve; 6, the anterior or aortic, and 6′, the posterior or parietal segment of the mitral valve (in the angles between these segments are seen smaller lobes); 7, the pulmonary artery; 8, placed upon the root of the aorta; 9, the right; 9′, the left coronary artery.

fashioned in the ventricle on account of the greater pressure to be overcome in the aorta.

Four pulmonary veins enter the left auricle in man (*vide supra*), two from each lung opening close together into opposite sides of the cavity. To open the left auricle a cut should be made across the posterior surface from the right to the left pulmonary veins, and another shorter cut towards the front at right angles to this one. The *mitral* valve guarding the left auriculo-ventricular opening may next be floated up by pouring in water in a similar fashion to that directed above in the case of the tricuspid valve. *It has only two flaps instead of three*, but is

much stronger than the tricuspid valve in its structure; otherwise the construction of the two valves is much the same.

The left ventricle may be opened by an incision passing along both anterior and posterior surfaces parallel and close to the inter-ventricular septum. When the flap so formed is turned out, the interior of the ventricle is seen. The cavity is longer and more conical in shape than that of the right ventricle. Similarly to the right ventricle it has two orifices, one leading *from* the auricle, the other *into* the aorta. The walls are also roughened by muscular projections, except near the mouth of the aorta where they are smoother. The *musculi papillares* of the left ventricle, giving attachment to the *chordæ tendineæ* at one end, are strongly developed, and arranged in two large bundles which spring respectively from the right and left sides of the cavity. The aortic opening is situated somewhat higher up and more to the front than the auriculo-ventricular, and both these orifices are slightly narrower than those on the right side. The entrance to the aorta is guarded by the *aortic semilunar valve*, which like that at the pulmonary artery has three pouch-like flaps, but is of stronger construction. The pouches in each case are folds of the inner coat of the artery strengthened by strong fibrous tissue. Where the three flaps meet in the closed position of the valve there are small nodules of cartilage called the *corpora Arantii.* Opposite each pouch of the valve there is a swelling outwards of the wall of the vessel known as the *sinus of Valsalva*, and at the upper margins of two of these sinuses, two openings are situated, which are the orifices of the *coronary arteries.* These arteries, the first branches of the aorta, supply the heart itself with blood. The veins of the heart open into the right auricle by various openings, but chiefly by the coronary sinus, situated between the inferior cava and the auriculo-ventricular opening. This course *viâ* the coronary artery, heart capillaries, and coronary sinus is the shortest circuit that the blood can take in the systemic circulation; while that to the capillaries of the intestine, from these to the capillaries of the liver by the portal vein, and back to the inferior cava by the hepatic vein, is the longest route which can be taken.

CHAPTER VI.

THE BLOOD.

THE nutrient fluid which circulates in the blood-vessels varies in colour from bright red to dark purple, according to the amount of oxygen which it contains.[1] It is very opaque, even in thin layers, and its opacity is due to the same cause as makes clouds or sea foam opaque though made up of transparent material, namely, that it contains floating in it myriads of minute particles (called *corpuscles*) which reflect and refract the light in all directions and refuse to allow it any passage in unbroken lines. A small drop of blood drawn from the finger ought to be examined by the student under the high power of a good microscope, preferably after diluting it with about its own volume of physiologically normal saline,[2] for the corpuscles in the blood are so numerous that they cannot be quite so clearly seen in undiluted blood.

A large number of small round discs are seen, which are occasionally discovered rolled over on their edge, when they are seen to be bi-concave in outline (see *r*, Fig. 67). They have a tendency to adhere by their concave surfaces, when these come in contact, so as to form long *rouleaux*. In colour they are a

[1] The bright red blood contains more oxygen, and is seen when an artery is cut through; since it is contained in the arteries it is called arterial blood. The dark purple colour is acquired as the oxygen disappears from the blood, which it does in the passage through the tissues, and hence the veins contain such blood, which is accordingly termed venous blood.

[2] This solution is easily made by dissolving 6·5 grams of common salt in a litre (1·76 pint) of tap water; for frog's blood, which is also well worth examining, it must be stronger (8 grams per litre). This solution has approximately the same strength in salts as the blood, and prevents alterations in shape of the corpuscles; water makes them swell out, and stronger salt solutions draw the water out of them and make them become shrunken and crenated.

pale yellow, for it is only when seen *en masse* that the colouring matter (*hæmoglobin*) with which they are charged has a red hue. There are immense numbers of these red blood corpuscles, or blood discs, in the blood, the average number being five to six millions per cubic millimetre,[1] but in anæmia the number may be much reduced.

There are, in addition to the red corpuscles, a much smaller

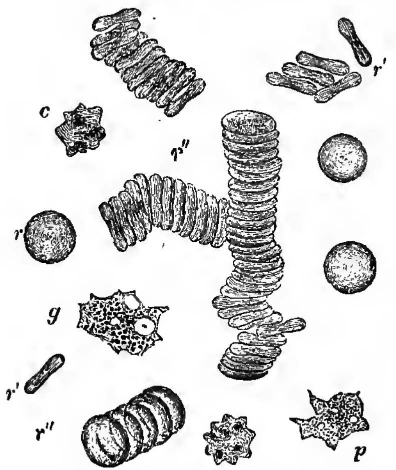


FIG. 67.—Human blood as seen on the warm stage. (Magnified about 1200 diameters.) (E. A. S., Quain's "Anatomy.")

r, *r*, single red corpuscles seen lying flat; *r'*, *r'*, red corpuscles on their edge and viewed in profile; *r''*, red corpuscles arranged in rouleaux; *c*, *c*, crenate red corpuscles; *p*, a finely granular pale corpuscle; *g*, a coarsely granular pale corpuscle. Both have two or three distinct vacuoles, and were undergoing changes of shape at the moment of observation; in *g*, a nucleus also is visible.

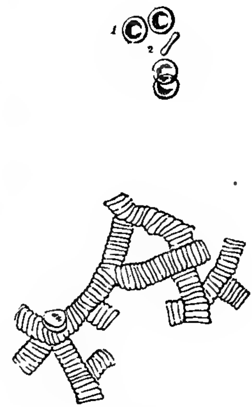


FIG. 68.—Human red corpuscles lying singly and collected into rolls. (As seen under an ordinary high power of the microscope.) After Henle and Wagner. (Quain's "Anatomy.")

1, on the flat; 2, in profile.

number of *white corpuscles*, or *leucocytes*. There is, on an average, one of these white corpuscles to every four hundred of the red corpuscles; they are usually considerably larger, in human blood, than the red corpuscles, although they vary greatly both in size and appearance. Each possesses one or more nuclei; some are vacuolated, and others granular, while others

[1] A cubic millimetre has about the volume of a large pin's head.

again are clear or nearly *hyaline.* They exhibit those amœboid movements which have been described in the introduction to this book, *especially when warmed*, and if the blood be mixed with fine particles, such as yeast cells, the white corpuscles may be observed with the microscope taking these into their mass. This *inception* of foreign particles indicates an important function of the white blood corpuscles. In a similar manner they absorb and render innocuous any deleterious particles which may have found their way in any manner into the blood. They congregate round a wound or other infected part, and prevent injurious products from entering the blood. In the combat many of the leucocytes themselves become poisoned and die, so that they are found in large number in the *pus* flowing from a suppurating wound.

The leucocytes are probably formed in the lymphatic glands, and enter the blood-stream with the lymph, for the number of leucocytes in the lymph is much increased after it has flowed through a lymphatic gland; also, the leucocytes of lymph have a preponderance of smaller and clearer cells, which are termed *lymphocytes*, and have the appearance of young leucocytes.

The purpose of the red blood corpuscles is to absorb oxygen in passing through the lungs and give it up again in passing through the tissues. About ninety per cent. of their dried weight consists of a complex substance of a *proteid* nature,[1] called *hæmoglobin*,[2] which is capable of forming an unstable chemical compound with oxygen. This compound is formed when the pressure of oxygen in the fluid containing the hæmoglobin reaches a certain value, and is decomposed again when the oxygen pressure falls. Now, in the tissues, oxygen is being constantly used up by the oxidations going on there, and consequently there is a low oxygen pressure; while in the lungs, by the process of respiration, the oxygen pressure is kept fairly high. Accordingly, the hæmoglobin takes up oxygen in

[1] The student is advised to read the part of chapter vii. *on the chemistry of proteid*, before reading this chapter.

[2] The name hæmoglobin is used in a general sense; when combined with oxygen it is often termed oxy-hæmoglobin, and when free of oxygen so combined it is termed reduced hæmoglobin. In addition to the usual proteid constituents it contains iron.

the lungs, and gives it up again in the tissues. Thus, a supply of oxygen is carried by the blood-stream to all parts of the body to serve in oxidizing, in the life processes of the cells, those nutrient materials which the blood also carries to the tissues.

The hæmoglobin can be set free from the corpuscles in various ways, such as, often alternately freezing and thawing, adding excess of water, or a trace of ether or chloroform. It then dissolves in the water of the blood and forms a transparent fluid of a deep lake colour known as *laked blood.*

The corpuscles of man and of the mammalia generally are, as stated above, non-nucleated bi-concave discs; but those of lower vertebræ (such as amphibia, fishes, and birds) are oval bodies with prominent nuclei. *Nucleated red blood corpuscles are, however, found before birth, even in the mammalia.* Red blood corpuscles are probably formed in large numbers, during life, in the red marrow of the ribs and of the heads of the long bones, and, as before stated, it is probable that they are, to some extent, destroyed in the spleen. The liver also probably takes a share in the disintegration of effete red blood corpuscles, for the bile pigments excreted by it are closely allied to hæmoglobin in their chemical constitution (see p. 164).

The corpuscles float in a clear fluid, which is of a pale straw colour when it is obtained uncontaminated by hæmoglobin shed from the red corpuscles, and is called the *plasma*, or *blood plasma.*

Special precautions must be taken in order to obtain plasma, because it possesses the property of *coagulating*, or setting into a solid mass. If this coagulation takes place in shed blood before the corpuscles have had time to subside and separate, a thick solid mass of blood, known as a *blood-clot*, is the result. The power of the plasma to undergo spontaneous coagulation after the blood is shed, and so to cause the blood to set solid, is a most invaluable quality; for, without it, an animal would slowly bleed to death even from an insignificant wound. By its aid, however, the apertures of the wounded vessels are stopped, and the leakage of blood ceases.

As will be presently pointed out, the coagulation of the

blood is due to a proteid dissolved in the plasma, called *fibrinogen*, which, under certain conditions, gives rise to an insoluble substance (also a proteid) called *fibrin*. The fibrin so formed when blood clots is but an insignificant part of the blood, amounting to only about two parts in a thousand; but, as it appears as a meshwork of long filaments, it converts the whole into a general jelly-like mass, which has a still more solid appearance if it is formed of the whole blood, so that the corpuscles are included in the meshes.

The clotting of blood—that is, the formation of the insoluble fibrin from the soluble fibrinogen—is affected by various circumstances, some of which retard or entirely prevent it, while others accelerate it. A study of these has thrown some light on the nature of the changes that occur; they may be summarized as follows:—

1. *A certain optimum temperature, corresponding with that of the body or a little over it, is most favourable for coagulation.* As the temperature sinks below this point, the speed of coagulation diminishes until at the temperature of melting ice it becomes infinitely slow, so that blood may be kept at 0° C. for days without undergoing coagulation. During this period, the corpuscles, which are heavier, sink to the bottom, and the clear yellow plasma appears above them. When they have completely subsided, the moist corpuscles occupy about one-third of the volume. If this *iced plasma* be decanted off and allowed to gain the ordinary atmospheric temperature, it slowly coagulates; if it be heated in a water bath to the temperature of the body, it coagulates much more rapidly. It hence contains all the necessary factors for coagulation, but their interaction is prevented by the low temperature.

2. *The presence of an excess of neutral salts, such as sodium or magnesium sulphate, delays, and in sufficient quantity prevents, the coagulation of blood.* Hence plasma may be obtained by drawing off the blood from an artery into a sufficient amount of a saturated solution of such a neutral salt. To prepare such *salted plasma*, about one-third as much of a saturated solution of sodium or magnesium sulphate is taken as there is blood expected, and the blood is mixed, by stirring, with this fluid

as it flows out of the blood-vessel.[1] This plasma coagulates when diluted, and still more rapidly if it be heated and have a portion of blood-clot from another source, or of blood serum,[2] added to it. It is of service in investigating the problems of coagulation, because the fibrinogen which causes coagulation may, by certain means, be separated from it.

3. *Blood may be prevented from coagulating by removing its calcium salts,*[3] *or converting these into an insoluble form.* This may be done by mixing the blood with a solution of a soluble oxalate (about 0·2 grammes of potassium or ammonium oxalate to each 100 cubic centimetres of blood) when *oxalate plasma* is obtained. This clots when excess of a soluble calcium salt is added to it, especially on warming.

4. Certain substances, such as "*Wittes' peptone*,"[4] *leech extract*, and *mussel extract*, if previously injected into a vein of a living animal, prevent the clotting of its blood when this is drawn soon afterwards. Plasma prepared by this method is called *peptone plasma.*

5. Certain other substances when injected into the veins, on the other hand, cause coagulation to set in within the living blood-vessels (*intra-vascular coagulation*). These substances can be extracted from the testis or thymus, or other glands rich in cell-nuclei; they were named *tissue fibrinogens* by their first discoverer (Wooldridge), but are probably derived from the nuclei of the cells of the gland extracted, and belong to a class of compounds known as nucleo-albumins.

6. Contact with foreign bodies, especially if these have roughened surfaces, hastens clotting, and remaining in contact

[1] The preparation of the plasma in this, as in some other methods given in the text, may be hastened by separating the corpuscles by means of the centrifuge.

[2] Blood serum is what is left of the plasma after the clot has separated; it is the clear fluid which separates from a blood-clot some time after it has formed.

[3] Blood-plasma, like the other fluids of the body, always contains a *trace* of soluble calcium salts. In the preparation of "oxalate plasma," these are not removed by filtration, but only thrown out of solution by the addition of excess of a soluble oxalate.

[4] A mixture of albumoses and peptone, obtained as a result of the peptic digestion of proteid (see p. 148); the anti-coagulative action is due to the albumoses p.esent, and not to the peptone.

with the blood-vessels, delays it. Blood drawn off into an oiled vessel is much longer in clotting than when drawn into a dry vessel; it remains still longer fluid if drawn off in drops into a quantity of oil. Again, if the large jugular vein of the horse be ligatured at two places some distance apart, so as to be full of blood,[1] and removed, the blood will remain fluid within the vein usually for some days, and plasma can be obtained from it,[2] which soon clots when drawn off into another vessel. The blood does, however, occasionally coagulate even within the vessels, and is usually found clotted in the heart soon after death.

7. Addition of old blood-clot to a sample of blood or plasma which only clots slowly, hastens the process.

Fibrinogen, that proteid of the plasma which causes coagulation of the blood, can easily be obtained from any of the forms of plasma of which the mode of preparation has been indicated above by adding to them an equal volume of saturated sodium chloride solution, that is, by half saturation with sodium chloride. The fibrinogen appears as a flocculent precipitate, which may be washed with some half-saturated sodium chloride solution, and then re-dissolved by adding distilled water,[3] which forms a dilute saline with the adhering sodium chloride. After being reprecipitated, washed, and redissolved several times, the fibrinogen is finally obtained in fairly pure solution. It does not clot spontaneously, in this condition, however long it be kept at a favourable temperature, but only after two things have been added to it. One of these is a soluble calcium salt, and the other is the material known as "fibrin ferment."

Fibrin ferment is formed after the blood has been shed, and is believed to be derived from the nuclei of the white blood corpuscles as these disintegrate. Like those substances which cause intra-vascular clotting when injected into the veins of a living animal, it belongs to the class of proteids called nucleo-proteids, which are found in cell nuclei. This ferment, or enzyme, in the presence of a soluble calcium salt, converts the

[1] To attain this object, the ligature nearer the heart must first be tied, then the other one.

[2] This experiment was first performed by Hewson, and is known as the *living test-tube experiment.*

[3] "Distilled" in order to avoid adding calcium salts.

fibrinogen of the plasma into an insoluble substance called fibrin. When the fibrin includes the blood corpuscles in its meshes, a blood-clot is the result. If the blood be whipped with a feather, or a bundle of twigs or wires, the fibrin of the blood separates on this, and may be washed and preserved. After its removal the blood does not clot, and is known as *whipped blood.*[1] After blood has clotted, a clear yellow fluid, which does not clot again, is gradually forced out from the mass of the clot; this fluid is *blood serum.*

Serum differs in composition from plasma only in that it contains no fibrinogen; for this has all been converted into fibrin, and remains in the clot. It is more easily obtained than plasma, and since it differs so little in composition, may be used to study the properties of the nutrient fluid in which the blood corpuscles float. It contains about ten per cent. of proteid, of which about half is a proteid called *serum-globulin,* which is precipitated by completely saturating the serum with magnesium sulphate, by adding crystals of that salt, or else by half saturating with ammonium sulphate by adding an equal volume, to the serum, of the saturated solution of that salt. The remainder of the proteid is a mixture of substances closely allied to one another, and termed serum-albumins; these are not precipitated on saturation with magnesium sulphate, or half saturation with ammonium sulphate, but are precipitated on complete saturation with ammonium sulphate.

Another method of separating these two forms of proteid is to place the serum in a dialyzing tube, made of parchment paper, round the outside of which a current of water is made to flow. The inorganic salts of the serum pass through the parchment paper, but the proteids cannot pass, and so remain within the dialyzer. As soon as the salts have been removed, the serum-globulin is precipitated; for the globulins are insoluble in water alone, and only remain soluble in blood plasma because of the inorganic salts which it also has in solution. The serum-albumins remain in solution, and can be separated by filtration. Afterwards, the globulin precipitate can be redissolved in dilute saline solution.

[1] Whipped blood is the serum with the corpuscles suspended in it.

The serum also contains about two parts per thousand of dextrose, or grape sugar, which serves as carbohydrate food for the tissues. It does not contain fat globules, unless it be obtained immediately after a fatty meal, when it may be quite milky from suspended fat.

The chief inorganic salts are sodium chloride, which is present in largest amount (six parts per thousand) sodium carbonate and sodium phosphate, and traces of calcium salts. It is to the mixture of sodium carbonate and phosphate that serum owes its alkaline reaction. Potassium salts are present only in traces, but are present in greater amount in the corpuscles and in the cells of the tissues.

Besides these substances, the serum contains very small amounts of other organic substances, the products of tissue activity, which are kept down to a minimum by being either excreted by the kidneys in the urine, or converted into other substances as the blood passes through the liver.

CHAPTER VII.

DIET, DIGESTION, ABSORPTION, AND METABOLISM.

THE supplies of nutrient materials which the blood carries round to the various tissues and organs of the body are prepared from the food of the animal by a process called *digestion.* While undergoing digestion, the food slowly passes along a tube called the alimentary canal, which is really an invagination or folding in of the outer surface of the body; straight in its upper and convoluted in its lower part. Hence, during the process of digestion, the food is not really within the body, but only within a hollow tube which passes through it, and it is only after being digested, and having passed through the walls of this alimentary canal that it really enters the body. The indigestible portion which cannot be absorbed, as well as a *small* amount of material excreted into the alimentary canal by certain glands (chiefly the liver), is finally ejected from the canal at its lower end.

A number of glands pour their secretions into the alimentary canal at various points along its length, and these secretions contain substances which act on the various constituents of the food, and form from these soluble products which are easily *absorbed* or taken up by the cells lining the walls of the alimentary canal, and after undergoing certain modifications in their passage through these cells are passed onwards to finally reach the blood-stream. This process of absorption takes place chiefly from the lower part of the alimentary canal —that is, from the intestine. It may be well, before treating of the process of digestion, to briefly summarize the steps by which the animal's food is prepared for it by other natural processes.

The sun is the fundamental source of all that energy in the

form of organic life which we see exhibited by the teeming myriads of plants and animals inhabiting our planet. Not only is this true in the sense that without the warmth of the sun's rays all life on the earth would be impossible, but in the narrower sense that every act of a living creature requiring the expenditure of energy is carried out by energy which has been stored up from the solar rays. The solar energy is converted first into chemical energy by the agency of living plants. Every green plant is a laboratory in which the energy of the sunlight is transmuted into the energy of chemical substances, which can afterwards, it may be, serve in the form of food as a source of energy for the supply of an animal, or after elaboration in the body of one animal may supply food (*i.e.* chemical energy) to another animal.

Plants form their substance from inorganic materials. They build up from these simple bodies others much more complex in their nature, which are capable in passing back again to the simple inorganic forms of giving out a supply of energy which may exhibit itself in other forms, such as heat and muscular work.

The process of formation of the more complex substances is spoken of as *reduction* by the chemist. In it energy is required, and it can only take place when some source of energy is available (sunlight in the case of plant life). The opposite process in which the simpler substances are again formed is spoken of as *combustion* or *oxidation*, because usually oxygen [1] is used up in the process. Here energy is set free, and is perceptible, if the oxidation takes place in the body of an animal, in the heat which maintains the animal's temperature above its surroundings, and in the muscular movements which are continually taking place.

In plants, then, processes of reduction go on, and from very simple bodies others of complex chemical nature are

[1] A gas forming about one-fifth of the atmosphere, which combines with bodies when these burn (or are oxidized), so giving rise to bodies (oxides) with a less store of chemical energy than the original bodies. The chemical energy so dissipated takes the form of heat, light, electricity, sound, muscular movement, or one other of the forms of energy; for energy can never be destroyed, but merely transmuted from one form to another.

formed by the aid of energy derived from the solar rays. In animals this store of energy is taken possession of; the animal, after various preliminary processes, absorbs into its body the complex materials forming the substances of the plants, and these are gradually oxidized (by means of oxygen taken in by the lungs) in the body back to simpler bodies. In the process of oxidation the solar energy, which had been stored up by the plant as chemical energy, is again set free in the form of heat and of muscular work, by means of which the animal is enabled to carry on its existence. It must not, however, be rashly supposed that in plants the life processes are purely reductions and accumulations of energy, and in animals the reverse. It is only true that the total effect in a plant is a preponderance of reduction and an accumulation of chemical energy, and in an animal the opposite is true; but at the same time the reversed processes, only in less degree, go on in the two kingdoms of life.

To enter a little more into detail, plants take up carbon dioxide from the atmosphere, which contains that gas to the extent of three to four parts per ten thousand, and by the aid of sunlight assimilate the carbon of the carbon dioxide, and set free its oxygen. From the supply of carbon so obtained, and the water of their tissues, plants build up more and more complex organic substances; also with the addition of nitrogen salts obtained from the soil even more complex organic substances containing nitrogen are formed. These nitrogenous organic bodies form an indispensable item of animal food, and are known as vegetable proteids. Although the organic bodies found in the dried substance of plants are very numerous, by far the greater weight of their organic material belongs to one of three great classes of organic bodies, which are termed *carbohydrates*, *fats*, and *proteids*.

In carbohydrates the elements present are *carbon*, *hydrogen*, and *oxygen*. Of these elements, hydrogen and oxygen are present in the exact proportions required to form water,[1] and

[1] It must not be supposed, however, that water is present in the carbohydrate molecule. The hydrogen and oxygen happen to be present in the same proportion as they are present in water; but they are combined with the carbon in a complex manner, and not so as to form water.

the ratio of the carbon to the hydrogen and oxygen is variable in the different groups of the class. When carbohydrates are burnt, since there is sufficient oxygen in the molecule to combine with all the hydrogen, oxygen is required only for the carbon, and as much carbon dioxide is formed by volume as there is oxygen used up. Hence, if an animal could be fed purely on carbohydrates, it would give out as much carbon dioxide by its lungs as it took in oxygen. In the case of the other two classes of food-stuffs (fats and proteids), there is *not* enough oxygen in the molecule to combine completely with all the hydrogen present to form water during combustion. Hence some of the oxygen taken in by the lungs combines in the tissues with this excess of hydrogen to form water, and only the remainder which combines with the carbon reappears, in the carbon dioxide exhaled by the lungs, in gaseous form. When fats and proteids are present in the food, therefore, as they always are, there is less carbon dioxide given out by volume through the lungs than there is oxygen taken in. The ratio of carbon dioxide given out to oxygen taken in is spoken of as the *respiratory quotient;* it is increased by carbohydrate, diminished by proteid, and still more by fatty food.[1]

The chief groups of carbohydrates are *glucoses*, *saccharoses*, and *amyloses*, or *starches.*[2]

The *glucoses* ($C_6H_{12}O_6$) are the simplest members; examples of them are *dextrose*, or *grape sugar*, and *lævulose*, which is formed in the inversion of cane sugar.

The *saccharoses* ($C_{12}H_{22}O_{11}$) are somewhat more complex in constitution; when treated with dilute mineral acid they are decomposed into glucoses (inversion). Examples are *cane sugar*, *maltose*, and *lactose*, or *milk sugar*.

The *starches* [$(C_6H_{10}O_5)_n$] are much more complex than either the glucoses or saccharoses, into which they become converted when they are either boiled with dilute mineral acids, or are treated with certain ferments contained in the digestive juices. Examples of starches are the ordinary potato and rice

[1] It is obvious from the above that the respiratory quotient never can exceed unity.

[2] A more recent terminology is mono-saccharides, di-saccharides, and poly-saccharides.

starch of commerce. The only starch occurring in the animal body is a substance called *glycogen*, or *animal starch*, which is found in the liver, and to a less extent in the muscles. Glycogen accumulates temporarily in the liver after carbohydrate food, being gradually converted into sugar, and used up in the tissues afterwards.

The *fats* contain the same three elements as the carbohydrates, but, as stated above, in quite different proportions. Chemically, the fats are glycerides—that is, they are formed by a combination of glycerine with a fatty acid or acids. The fatty acid present has a large number of carbon and hydrogen atoms in its molecule, and is hence a very weak acid. To this weak fatty acid the glycerine behaves as a base, so that the fats are neutral bodies. There are three chief fats present in the animal body, viz. *olein*, *palmitin*, and *stearin*. These three bodies have different melting-points, and, according to the proportion in which they are mixed, give rise to the different physical and other characters which distinguish the fat of different species of animals.

The *proteids* are, in their chemical composition, the most complex class of bodies found in the animal body. They consist of carbon, hydrogen, oxygen, nitrogen, sulphur, and sometimes phosphorus, united in proportions which vary somewhat for different members of the class. Their chemical constitution is at present unknown, but it is certain, from various properties which they possess—such as inability to diffuse through membranes, small percentage of sulphur or phosphorus, and large number of decomposition products—that they possess high molecular complexity. Proteids form the chemical basis of protoplasm, and are hence present in every living cell of the body. For the same reason they are an indispensable form of food for all animals, since they are necessary for the repair of protoplasmic waste. Thus, while an animal can be kept alive when fed on proteid alone, and denied all fat or carbohydrate, its life cannot be sustained on a diet of pure fat or pure carbohydrate, or a mixture of these two food-stuffs.

Proteid might, therefore, be designated as an essential food, and carbohydrate and fat as accessory foods, but that this would

minimize too much the importance of fats and carbohydrates as food-stuffs. For, although an animal can be kept alive on *proteid alone*, this *forms a very inefficient and imperfect diet.* A part of the proteid so eaten goes to do work which can be much better done by carbohydrate or fat. Just as the chief purpose of the proteid of the food is to renovate the cell protoplasm, to repair the waste of cell substance, the chief use of carbohydrate and fat is to supply chemical energy for cell activity. When, for example, a muscle contracts, it does so mainly at the expense of chemical energy supplied by the combustion in the muscle of carbohydrate material. In the absence of carbohydrate, proteid may be used as a source of energy, but it is less effectual, and there is a waste in its application. When the muscles are set hard at work contracting, as when prolonged exercise is taken, if a sufficient supply of carbohydrate and fatty food be given, there is found to be little increase in the amount of proteid used up in the body, but a considerable increase in the amount of fat and carbohydrate used.[1]

The only difference in importance, then, between proteid on the one hand, and carbohydrates and fats on the other, is that proteids alone can repair protoplasmic waste.

A proper diet hence consists of a judicious mixture of the three great classes of foodstuffs, and this is the dict which we naturally select in the mixture of foods which we eat from day to day.

The digestive apparatus of man is intermediate in type between that of herbivora and that of carnivora, as is shown by the form of the teeth and the length of the alimentary canal. Such a natural condition of affairs indicates a mixed diet of flesh and vegetables as the best suited for our consumption.

[1] This is shown by determining the amount of urea (the end product of proteid change in the body) excreted while the amount of muscular work is varied. The excretion is then found to be little changed, the increase being quite insufficient to account for the work done, and merely representing the increased wear and tear on the protoplasm. On the other hand, the amount of carbon dioxide given off from the lungs is found to be largely increased, thus pointing to an increased consumption of carbohydrate or fat.

The objections urged by vegetarians on ethical grounds against the slaughter of animals for food are utterly opposed to natural law. For there are whole classes of animals which can only exist on animal food, and throughout nearly the whole of the animal world one species preys upon another; the stronger attacking, killing, and devouring the weaker. Indeed, animal life cannot be maintained except by preying on other forms of life; the animal organism, *of whatever type it be*, cannot prepare its food from inorganic sources, but must ultimately, directly or indirectly, sustain itself on plants, which are also living, and must die to supply its food. The diet used by an animal varies with many circumstances. It varies first of all with the class of animal. A herbivorous animal has a capacious stomach and intestine, and fares best with coarse, bulky food, such as vegetables, grass, and hay. A carnivorous animal has a much less capacious alimentary canal, the intestine is very short, and hence some food is necessary which contains a large amount of nutriment in an easily available form, and in a small bulk, so that it can be readily digested and absorbed. Such an animal, therefore, is best fed on flesh meat. The food varies again with the climate and time of year. Fats are the form of foodstuff, which produce in combustion the greatest amount of heat from a given weight, for they evolve nearly twice as much heat as an equal weight of either proteid or carbohydrate.[1] Hence in cold climates or in winter time much more fat is naturally taken in the food than in warm climates or in the summer.

The amount of food required by an individual varies with the extent of his exercise or labour. Hard work requires a liberal allowance of food, and with a sedentary occupation the amount of food must be diminished, or troubles of digestion and nutrition arise. About a quarter of the food daily taken is solid, and the remainder consists of water. Various normal diets have been given by different observers, but the conditions are so variable as to make these of little value. The two most often quoted are the following, which are given

[1] The heats of combustion of proteid and carbohydrate are very nearly equal.

in round numbers, in weights of dry solids, for an average man weighing 70 kilograms, or about 150 pounds :—Proteid, 120 grammes ;[1] fat, 50–100 grammes ; carbohydrate, 350–500 grammes (Voit) :—Proteid, 100 grammes ; fat, 100 grammes ; carbohydrate, 240 grammes (Ranke).

Besides the three classes of organic foodstuffs mentioned above, it is necessary to life that a supply of inorganic salts should be taken in with the food, for each day a considerable amount of these is excreted in the urine. These are in part contained in the food itself, and in part dissolved in the water which is drunk with it, while in addition we daily consume a certain amount of common salt with our food.

Movements of the Alimentary Canal.

The alimentary canal is lined, almost throughout its entire length, by muscular fibres, which are arranged in two coats. In the inner coat (that next the lumen of the tube) the fibres are disposed circularly round the tube to form the circular coat ; while in the outer coat the fibres are arranged parallel to the length of the tube, and constitute the longitudinal coat. It is by the contraction of these muscle fibres in turn that a wave of contraction is caused to pass along the tube, so gradually shifting onward the food which is undergoing digestion. The muscles of the cheek and pharynx, and of the upper part of the œsophagus, are striped ; but the muscle fibres lining the remainder of the alimentary track are involuntary, except at the anus, where the fibres of the external sphincter are striped.

Mastication, or chewing, consists in the comminution of the food by grinding it between the teeth, under which it is repeatedly placed by the action of the muscles of the cheeks and tongue. When the food has been sufficiently broken up by the teeth it is swallowed, and passes down the œsophagus into the stomach. In the process of *deglutition*, or swallowing, the food, which has been rolled into a rounded mass or bolus by the action of the cheek and tongue muscles, is slid back over the tongue, and carried back on the base of the tongue into the pharynx. So

[1] There are about 440 grammes in one pound avoirdupois.

far the process is voluntary, but the remainder is involuntary. While in the pharynx, and before it enters the œsophagus, the food is in the way of the air passing to and fro between the nose or mouth and the trachea, and hence during this second stage of its journey the muscular movements are very rapid, and respiration is suspended while they take place. The soft palate at the back of the roof of the mouth is raised, shutting off the nasal passage from the pharynx, and making a wide passage for the bolus of food; the trachea and its upper opening, the glottis, are pulled up in front beneath the base of the tongue, so as to prevent any possibility of food entering the trachea; the bolus of food is grasped in turn by each of three pairs of muscles, the constrictors of the pharynx, which contract upon it, and *force it downwards into the upper end of the œsophagus.* The third act in the process of deglutition consists in the passage of the food along the œsophagus to the stomach; this, in man, is assisted by the action of gravity, but it is easy to swallow upwards, and many animals habitually do so. The passage is caused by a *peristaltic* wave, which consists of an annular constriction passing along the œsophagus from its upper to its lower end, and forcing the food in front of it.

The peristalsis of the œsophagus differs from that of the intestine to be presently mentioned in that it takes place under the direct action of nerve impulse. If the œsophagus be ligatured or cut across, the wave passes the point, and is continued on uninterrupted on the other side. On the other hand, if the nerves to the œsophagus be cut, the peristalsis does not take place. In the case of the intestine the reverse is the case in both instances; section of nerves does *not* stop the peristalsis, but section of the muscle fibres does. Hence it is probable that the peristalsis of the œsophagus is a succession of reflex discharges of nerve impulses along the tube, while that of the intestine is a muscular contraction propagated from muscle fibre to muscle fibre.

In the stomach there is an oblique layer of muscular fibres interposed between the inner circular and the outer longitudinal coats. By slow peristaltic contractions of these various layers, which become more energetic one or two hours after a meal, the food is churned about in the stomach, and at a later period, by more forcible contractions, it is forced out at

intervals through the pylorus[1] into the duodenum, or upper part of the small intestine.

Slow peristaltic waves pass along the intestine in the form of annular constrictions, which move the food slowly down the intestine. These peristaltic waves may be well seen when the abdomen of a freshly killed animal is opened, for the cold of exposure increases them. They may be artificially started at any point by touching with the point of a knife. After a considerable pause, for the latent period is very long, an annular constriction begins at the point touched, and usually a constricted wave, which travels very slowly, passes from this point both up and down the intestine. These intestinal movements are stimulated and increased by the presence of food in the intestine, and are diminished, and gradually subside when the intestine has been empty of food for some time.

THE DIGESTIVE GLANDS.

The food while passing along the alimentary canal is acted upon by secretions, which are poured in at various points along the length of the canal. In some instances these secretions are poured in at the openings of comparatively large ducts, which carry the secretion that has been collected from large glands lying at some distance from the intestine. In other cases the glands are minute, and lie in great numbers in the inner or mucous coat of the canal, and their secretion is poured out by minute ducts upon the mucous membrane[2] which forms the inner surface. Examples of the former type of gland are the salivary glands, the pancreas, and the liver; and of the latter there are the gastric glands lying in the mucous coat of the stomach, and the glands of Lieberkühn, which are small tube-like glands embedded in the mucous coat of the intestine.

[1] The stomach is closed at its two openings (the cardiac orifice and pyloric orifice) by muscular rings called sphincters; that separating it from the œsophagus is termed the cardiac sphincter, and that separating it from the duodenum the pyloric sphincter. These rings are only relaxed in order to allow food to pass in or out of the stomach, and the food does not pass out continuously, but only at intervals when the pylorus is opened.

[2] The term *mucous membrane* is applied to a surface moistened by mucus which is secreted by some of the cells forming the surface. Such a mucous membrane lines the alimentary tract, as well as the respiratory and nasal passages, which may be regarded as prolongations or diverticula of it.

Besides these glands there are single cells in large numbers to be found in the inner lining layer of the intestine,[1] which, from their shape, are termed *goblet cells.* These goblet cells secrete mucus, which moistens the surface of the intestine, and may be regarded as the simplest type of gland to be found in the body. In the arrangement of their cells, the salivary glands and the pancreas are what is known as *racemose* glands. The cells which furnish the secretion are aggregated in little lobules

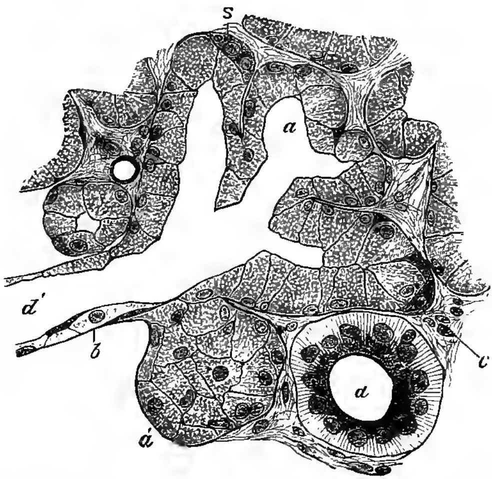


FIG. 69.—Section of the submaxillary gland of the dog, showing the commencement of a duct in the alveoli. (Magnified 425 diameters.) (E. A. S., Quain's "Anatomy.") *a*, one of the alveoli, several of which are in the section shown grouped around the commencement of the duct *d'*; *a'*, an alveolus, not opened by the section; *b*, basement-membrane in section; *c*, interstitial connective tissue of the gland; *d*, section of a duct which has passed away from the alveoli, and is now lined with characteristically striated columnar cells; *s*, semilunar group of darkly stained cells at the periphery of an alveolus.

or bunches, which are composed of smaller groups of cells called *acini* or *alveoli.* In each acinus the cells are arranged round a central minute duct, or *lumen*, which serves to carry off the small quantity of secretion furnished by the acinus. The minute ducts leading from the acini unite with one another to form larger ducts, which again unite, until finally there is

[1] Such cells are also found amongst the ciliated cells of the trachea and bronchi, and in other similar situations.

formed one chief duct, which carries the entire secretion of the whole gland. The whole structure is thus somewhat like a tree branch or a bunch of grapes in its arrangement, and it is for this reason that such glands are called *racemose.*

An idea of the arrangement of the cells in such a gland may be gathered from the accompanying drawings, which show the appearance presented by thin sections of the submaxillary

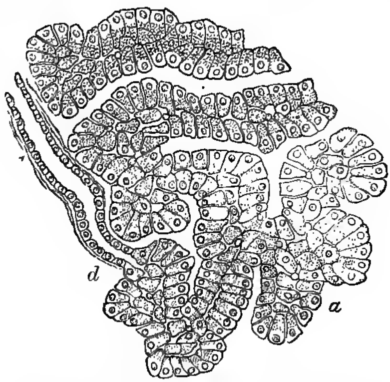


FIG. 70.—Section of the pancreas of the dog. (Klein.) *d*, termination of a duct in the tubular alveolus, *a*.

salivary gland and of the pancreas of the dog. In the salivary glands the ducts are more numerous than in the pancreas. The alveoli, or acini, are also much shorter and more rounded in the salivary glands than in the pancreas, where they form long columns of cells. The bile duct, which carries the bile from the liver to the duodenum, arises in a similar branching fashion from the lobules of the liver. But the secretion of bile is not the main function of the liver, as that of the saliva is of the salivary glands; it has other important work, which will be indicated later.

There are three pairs of salivary glands, known as the *parotid*, *submaxillary*, and *sublingual* glands respectively, and besides these there are a large number of much smaller glands lying beneath the mucous membrane of the mouth, and opening upon it by minute ducts.

The *parotid* gland (see Fig. 71) is the largest of the three salivary glands and weighs nearly one ounce (20 to 30 grammes). It lies in front of and below the ear, and extends deeply into the cleft behind the ramus of the lower jaw.

FIG. 71.—Sketch of a superficial dissection of the face, showing the position of the parotid and submaxillary glands. (Allen Thomson.) $\frac{2}{5}$

p, parotid gland; *p′*, socia parotidis; *d*, the duct of Stensen before it perforates the buccinator muscle; *a*, transverse facial artery; *n*, *n*, branches of the facial nerve emerging from below the gland; *f*, the facial artery passing out of a groove in the submaxillary gland and ascending on the face; *sm*, superficial portion of the submaxillary gland.

Its duct (Stensen's duct) leaves the gland at its anterior border, and runs forward in the cheek external to the masseter muscle, round the anterior border of which it turns and passes inward to open into the mouth on the inner surface of the cheek opposite to the second molar tooth of the upper jaw, where there is a small papilla.

The *submaxillary* gland is next in size, weighing about a

quarter of an ounce (8 to 10 grammes). It is ovoidal in form, and is situated below and to the inner side of the base of the lower jaw. The duct (Wharton's duct) leaves the gland posteriorly, and then turning forward and inward beneath the sublingual gland (see Fig. 72), it runs forward and opens into the mouth, close to its fellow of the opposite side, at the *frænum linguæ*, that band which binds down the tongue in front.

The *sublingual* gland (see Fig. 72) is much smaller than the other two. It lies in the floor of the mouth, covered only by

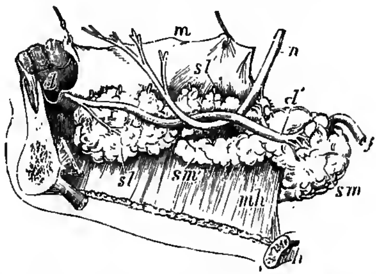


FIG. 72.—View of the right submaxillary and sublingual glands from the inside. (Allen Thomson.)

Part of the right side of the jaw, divided from the left at the symphysis, remains; the tongue and its muscles have been removed; and the mucous membrane of the right side has been dissected off and hooked upwards so as to expose the sublingual glands; *s m*, the larger superficial part of the submaxillary gland; *f*, the facial artery passing through it; *s m'*, deep portion prolonged on the inner side of the mylo-hyoid muscle *m h*; *s l*, is placed below the anterior large part of the sublingual gland, with the duct of Bartholin partly shown; *s l'*, placed above the hinder small end of the gland, indicates one or two of the ducts perforating the mucous membrane; *a*, the papilla, at which the duct of Wharton opens in front behind the incisor teeth; *a'*, the commencement of the duct; *h*, the hyoid bone; *n*, the lingual nerve.

mucous membrane, between the tongue and the gums of the lower jaw, where it forms a slight swelling. The sublingual gland has several ducts (ducts of Rivinus), which either open separately into the mouth or join Wharton's duct. One of these is often larger than the others and is termed the duct of Bartholin; it usually opens into the submaxillary duct.

The *saliva* is the mixed secretion of these various glands. It is a thick stringy or mucous fluid, which serves the double purpose of moistening the mouth and the food, and of coating each bolus over with a slippery envelope which facilitates its passage to the stomach. Its stringiness is due to the mucin which it contains; this may be precipitated from it by the

addition of a few drops of acetic acid.[1] Besides this physical action on the food, saliva has in herbivora and in man[2] a chemical action upon starch, which it converts into a sugar (*maltose*) and a mixture of dextrins.[3] This conversion is brought about by traces of a substance called *ptyalin* which it contains.

Ptyalin is the first example which we have met of those substances called unorganized ferments, or *enzymes*, to which the chemical changes in the food brought about by the digestive juices are due. These peculiar substances have not yet been isolated by the physiological chemist in a pure condition, so that their chemical nature is unknown. They exist only in traces in the several digestive fluids in which they occur, but are so powerful in their action that this is no disadvantage. The following are the chief general characteristics of their mode of action :—

1. They all act best at a certain temperature which is known as the *optimum temperature* ; as the temperature falls below this their action becomes less energetic and finally ceases. If the fluid, however, be warmed again they become active once more ; as the temperature rises above the optimum point the action also slackens, and at a certain temperature (60° to 70° C.) the enzyme becomes permanently destroyed and does not work again when the temperature is lowered.

2. They act best with a given reaction of the fluid and a definite degree of acidity or alkalinity. Most of them act in an alkaline medium, but *pepsin*, an enzyme of the gastric juice, acts only in an acid medium, and is rapidly destroyed by alkalies ; those which act in an alkaline medium are, on the other hand, destroyed by acids.

3. The action of all enzymes is *catalytic*—that is to say, they are not changed by the reaction which they induce, and an indefinitely small amount of enzyme will change an indefinitely large amount of substance, except in so far as it is lost by dilution. The action is probably, in most cases, one of *hydrolysis*, or the taking up of the elements of water.

[1] It remains dissolved in the saliva because of the alkaline reaction of that fluid.

[2] This action is wanting in typical carnivora.

[3] *Dextrins* are carbohydrates intermediate between saccharoses and starches in their properties.

4. The action of each enzyme is *specific*—that is, each particular enzyme acts only on one particular class of foodstuff, and not upon all three. The enzymes are classified according to the class of food-stuff they act upon, and the manner of their action upon it. *Amylolytic* enzymes act upon starches, and convert them into maltose and dextrins. *Inverting* enzymes act upon the compound sugars, and convert them into simple sugars. *Proteolytic* enzymes act upon proteids, and convert them into albumoses and peptones. *Steatolytic* enzymes act on fats, and convert them into fatty acids and glycerine. Besides these there are certain enzymes known which cause coagulation of fluids, such as *rennin*, which causes milk to clot, and *fibrin-ferment*, which produces blood coagulation.

The following table gives an enumeration of the chief enzymes of digestion, the fluids in which they are found, the reaction with which they work, and a summary of their action :—

Name.	Digestive fluid in which found.	Reaction of fluid.	Action on food-stuff.
1. Amylolytic enzymes:			
(*a*) *Ptyalin*	Saliva	Alkaline	Converts starch into maltose and dextrins.
(*b*) *Amylopsin*	Pancreatic juice	Do.	Do.
2. Inverting enzymes :			
(*a*) *Invertin*	Intestinal fluid [1]	Do.	Converts compound sugars such as cane sugar and maltose into simple sugars such as dextrose and lævulose.
3. Proteolytic enzymes :			
(*a*) *Pepsin*	Gastric juice	Acid	Converts proteids into albumoses and peptones.
(*b*) *Trypsin*	Pancreatic juice	Alkaline	Do.
4. Steatolytic enzymes :			
(*a*) *Steapsin*	Pancreatic juice	Alkaline	Converts fats into fatty acids and glycerine.
5. Coagulating enzymes :[2]			
(*a*) *Rennin*	Gastric juice	Alkaline, neutral, or faintly acid	Coagulates milk.

[1] Called "*Succus entericus.*"

[2] There is a ferment as yet not named found in pancreatic juice which also coagulates milk; similar ferments are also found in the juices of many plants.

The action of *ptyalin* on starch takes place in successive stages. At first, the starch is converted into a more soluble form, known as *soluble starch;* next, a body giving a red coloration with iodine, and called *erythro-dextrin*, is formed simultaneously with a certain amount of a sugar, called *maltose;* finally, there are formed gum-like bodies, called *dextrins*, which, since they give no colour with iodine, are called achroo-dextrins, and a larger percentage of maltose. Complete conversion into maltose never takes place, even after prolonged action of ptyalin. This action on starch is stopped about half an hour after the food has entered the stomach—as soon, that is, as the acid reaction of the first portions of gastric juice secreted has destroyed the ptyalin. The saliva contains, besides mucin and ptyalin, only a small amount of inorganic salts. The most remarkable of these inorganic salts is a trace of *potassium sulphocyanide*, which can be detected by allowing a drop of saliva to mix on filter-paper with a drop of very dilute ferric chloride, when a blood-red colour is usually produced.

The digestive secretion of the stomach is termed the *gastric juice.* This secretion is furnished by an immense number of minute glands lying in the thick mucous coat of the stomach, which pour their secretion out directly upon the mucous membrane. There are two types of gland found in the stomach. In one of these types there are two kinds of cell (see Figs. 74, 75). One kind of cell, which is by far the more numerous, lines the lumen of the gland, and lies centrally to the other kind; these cells are called *chief*, or *central* cells. The other kind of cell occurs at intervals, and is removed from the central lumen by the thickness of the row of chief cells; these cells are called *parietal*, or *oxyntic* cells. This type of gland occurs at the cardiac end, and also over the greater part of the stomach; it is known as the *cardiac gland.* The other type of gastric gland (*pyloric gland*) contains only one kind of cell, resembling the chief cell of the cardiac gland. It is also distinguished by having a much longer duct and shorter alveoli. These glands are confined to the pyloric end of the stomach. In connection with this difference in structure there is a corresponding difference in the character of the secretion of the two kinds of

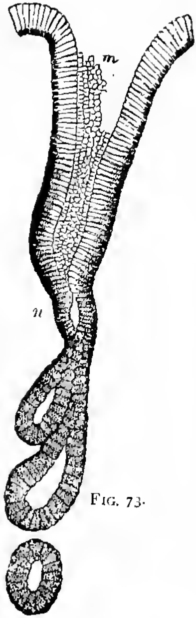


FIG. 73.

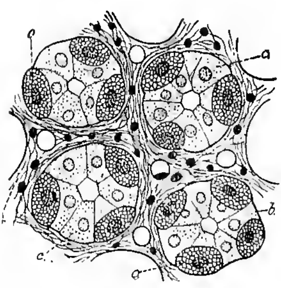


FIG. 74.

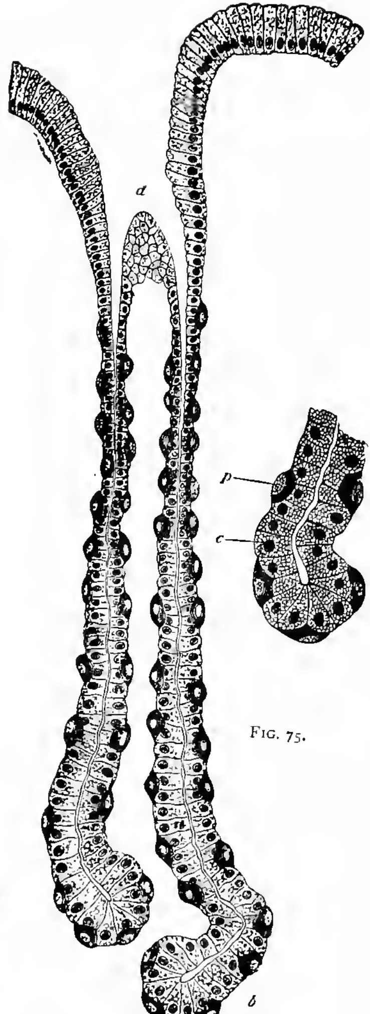


FIG. 75.

FIG. 73.—A pyloric gland, from a section of the dog's stomach. (Ebstein.) *m*, mouth; *n*, neck; *tr*, a deep portion of a tubule cut transversely.

FIG. 74.—Section of the gastric mucous membrane taken across the direction of the glands (cardiac part). *b*, basement membrane; *c*, central cells; *o*, parietal cells; *r*, retiform tissue (with sections of blood-capillaries) between the glands.

FIG. 75.—A cardiac gland from the dog's stomach. (Highly magnified.) (Klein.) *d*, duct or mouth of the gland; *b*, base or fundus of one of its tubules. On the right the base of a tubule more highly magnified; *c*, central cell; *p*, parietal cell.

gland. The two most important constituents of the gastric juice are *pepsin* and *hydrochloric acid*, and it has been shown that both these constituents are secreted by the cardiac glands, and only pepsin by the pyloric glands. Since the only kind of cell of the pyloric gland is very similar to the chief cell of the cardiac gland, it has been supposed that the chief cells secrete pepsin, and the parietal or oxyntic cells, the hydrochloric acid.

The gastric juice has little or no action on carbohydrates or fats, but acts energetically on proteids.

The chief enzyme is *pepsin*, which dissolves proteid, and converts it into substances which are afterwards readily absorbed by the cells lining the intestine. There are several stages in the peptic digestion of proteids. First the proteid is dissolved and rendered non-coagulable by heat, by conversion into acid albumin ; at this stage it is precipitated, if the solution be neutralized by dilute alkali. Next it passes into more soluble substances, called albumoses, which are not precipitated on neutralizing, and differs from the original proteids in several chemical tests. Finally, a portion of the albumose is converted into peptone, which is still more soluble and more easily absorbed by the intestinal cells, and here the process stops. The whole drift of the chemical changes is thus the preparation of a more soluble material which can be more readily absorbed.

The gastric juice contains a second ferment, called *rennin*, which has the property of curdling milk. The process bears a close resemblance to the clotting of blood (see p. 127); in both cases an unorganized ferment produces the clotting, and in both cases the presence of a calcium salt is necessary. The curdling of milk is probably not the only purpose of rennin in the stomach, for it is found in the gastric juice of fishes.

By the movements of the stomach and the digestive action of the gastric juice combined, the food is reduced to a soup-like mass, of varying consistency according to the nature of the food, which is called *chyme*. The chyme has a strongly acid reaction, due to the hydrochloric acid of the gastric juice. At intervals, portions of it pass through the pylorus into the duodenum, where they soon become mixed with those alkaline

secretions—*the bile* and *pancreatic juice*—which are poured into the intestine by two ducts,[1] opening close to each other about 3 or 4 inches below the pylorus. By admixture with these secretions, and with the alkaline mucus furnished by the goblet cells, the chyme soon acquires an alkaline reaction, and undergoes further attack by the unorganized ferments or enzymes of these secretions, which are all most active in an alkaline medium.

The *pancreatic juice* is the most important of the digestive secretions, containing as it does three distinct enzymes, each acting on a different one of the three great classes of food-stuffs.

Amylopsin completes that conversion of starches into maltose and dextrins which was temporarily arrested during gastric digestion. Its action closely resembles that of ptyalin (see p. 146), but is more rapid.

Trypsin finishes the digestion of proteids which was commenced by pepsin in the stomach. It differs from pepsin in that it acts in an alkaline medium, and in that its action is much quicker and more profound. The albumose stage is rapidly rushed through, so that it is impossible to isolate albumoses from an artificial tryptic digestion,[2] in the same way as from a peptic digestion. Further, if the action of trypsin be allowed to proceed the peptone formed is broken up into a number of simpler organic bodies.

Steapsin acts upon the fats of the food which have been previously freed of their enveloping connective tissue, through the action of the pepsin of the gastric juice upon it. It splits a portion of the fat up into fatty acid and glycerine, and the fatty acids so formed combine with the alkali present in the intestine to form soaps. In the soapy solution, the remainder of the fat usually becomes suspended in fine drops forming an

[1] In man the two ducts usually join before opening into the intestine, and then open by a common orifice, while in many animals there are two or even more pancreatic ducts.

[2] It is by means of artificial digestion in glass vessels that the properties of the several digestive fluids described in the text have been discovered. Either a quantity of the digestive secretion itself or an extract of the gland yielding it, is allowed to act on a portion of the food-stuff for a given time under favourable conditions of temperature and reaction, then the fluid is analyzed and the changes in it observed.

emulsion just as the fat of milk does. In this finely divided form the fat readily undergoes further attack by the steapsin, and is probably all converted in the end into free fatty acids and glycerine. In some animals all the free fatty acid combines with alkalies to form soaps, while in others the alkali present in the intestine is insufficient for the purpose, and the fatty acids which are insoluble in water are dissolved by the agency of the bile. In addition to the bile and pancreatic juice there is an alkaline fluid secreted over all parts of the mucous membrane of the intestine by small glands imbedded in it, which is called the *succus entericus*. The *succus entericus* is probably in great measure secreted by an immense number of minute glands called the *crypts or glands of Lieberkühn*. These are simple tubular invaginations of the surface of the mucous membrane lined with secreting cells (see Fig. 76); similar crypts are found in the large intestine, but in these mucin (goblet) cells are more common (see Fig. 77). Succus entericus is strongly alkaline in reaction, and contains an inverting ferment (*invertin*) which acts on the double sugars (saccharoses) and changes them into simple sugars (glucoses). In this way it attacks the maltose formed by the action of the saliva and pancreatic juice on the starch of the food, and changes each molecule of it into two molecules of dextrose. In a similar fashion it converts cane sugar into a mixture of equal parts of dextrose and lævulose.[1]

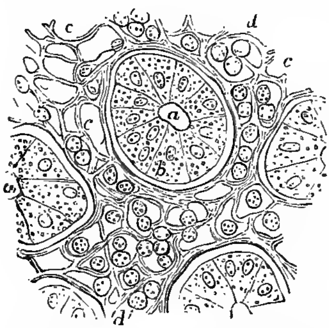


FIG. 76.—Cross-section of a small fragment of the mucous membrane of the intestine, including one entire crypt of Lieberkühn and parts of three others. (Magnified 400 diameters.) (Frey.)

a, cavity of the tubular glands or crypts; *b*, one of the lining epithelial cells; *c*, the interglandular tissue; *d*, lymph-cells.

The chemical changes in the food brought about by the

[1] The action is a hydrolytic one—that is to say, the elements of a molecule of water are taken up, as might be represented by the equation—

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$$

agency of these various digestive secretions are intended to adapt it for more easy absorption by the cells lining the intestine, by rendering it more soluble and diffusible so that it can more readily enter these cells.

We may next turn our attention to this process of *absorption*,

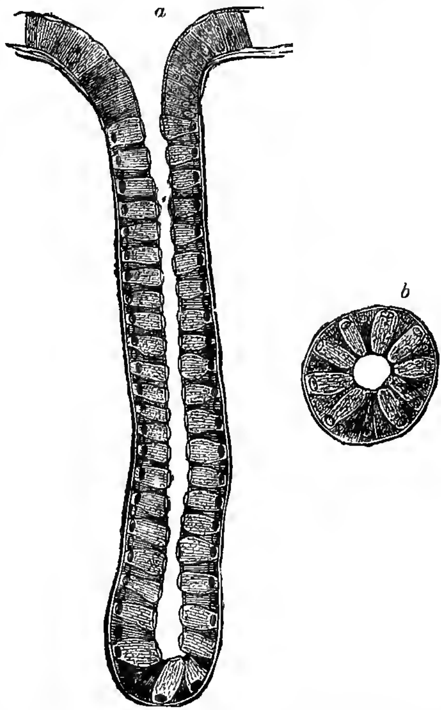


FIG. 77.—A gland of the large intestine of the dog. (From Heidenhain and Klose.) *a*, in longitudinal; *b*, in transverse section.

and it will be well in the first place to consider the arrangement of the absorbing structures. The digested food is in the first instance absorbed by the cells lining the alimentary canal, and is afterwards passed on, when it has undergone some modification in these cells, to the tissue underlying them. By far the greater portion of the food is absorbed in the small

intestine. The mouth and œsophagus are lined by stratified epithelium[1] resembling in structure that covering the body externally (the epidermis), only softer in its texture; such an epithelium is unsuitable for absorption, and practically none takes place. In the stomach this stratified epithelium is replaced by columnar epithelium, which in a single layer occupies the interspaces between the gastric glands and penetrates into them as a lining epithelium for their ducts. This epithelium seems more suitable for absorption, but the surface of the stomach is smooth, and hence has a much smaller area than that of the intestine which is vastly increased by finger-like projections upon it called *villi* (see Fig. 78). Further, the gastric columnar cells are found not to absorb most substances in solution in water, or only to absorb them very feebly; so that only a small share in the process of absorption is taken by the stomach. The intestine is also lined

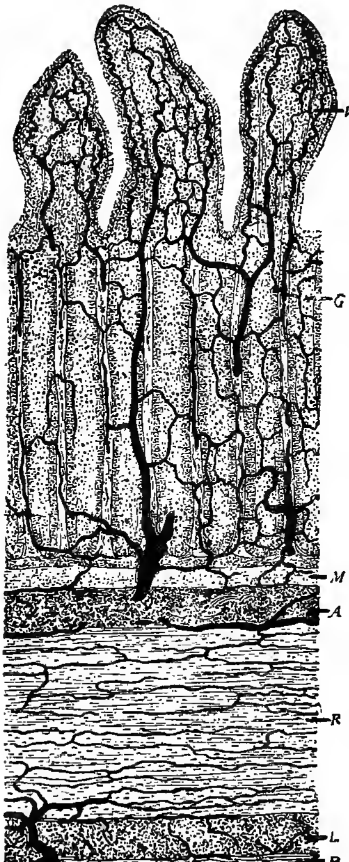


FIG. 78. — Small intestine, vertical transverse section with the blood-vessels injected. (Heitzmann.)

V, a villus; *G*, glands of Lieberkühn; *M*, muscularis mucosæ; *A*, areolar coat; *R*, ring-muscle (circular layer of muscular coat); *L*, longitudinal layer of muscular coat; *P*, peritoneal coat.

[1] Stratified epithelium means a lining or coating tissue in which the cells are many layers thick (see Fig. 92, p. 201).

throughout with columnar epithelium in a single layer, except at the rectum, where it again becomes stratified. In the small intestine the surface is not smooth, but is covered all over with minute projections like the piles on a piece of velvet. In this

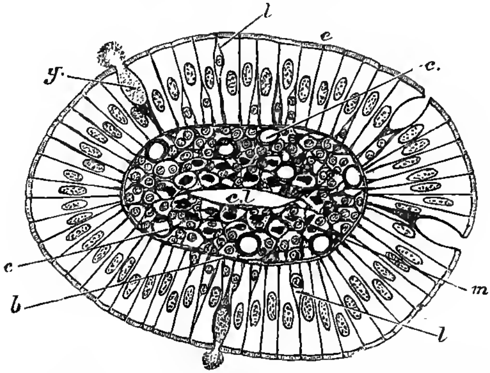


FIG. 79.—Cross section of a villus of the cat's intestine. (Highly magnified.) (E. A. S.)

e, columnar epithelium; *g*, goblet cell; its mucus is seen partly exuded; *l*, lymph-corpuscles between the epithelium cells; *b*, basement membrane; *c*, blood-capillaries; *m*, section of plain muscular fibres; *cl*, central lacteal.

way the surface through which absorption can take place is enormously increased, and the rate at which this process can go on is made correspondingly more rapid. Each of these little pro-

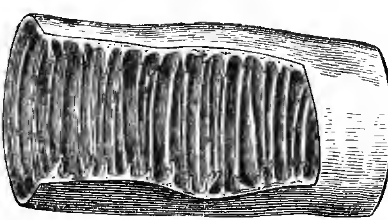


FIG. 80.—Portion of small intestine distended with alcohol and laid open to show the valvulæ conniventes. (Brinton.)

jections is called a *villus*. The structure of the wall of the intestine, the arrangement of the villi upon it, and the structure of a villus are shown in the accompanying illustrations. The intestinal wall, like that of the stomach, has four coats which,

enumerated from the outside to the inside of the tube, are called the serous or peritoneal, the muscular, the areolar or submucous, and the mucous coats.

The serous coat surrounds the intestine in the jejunum and ileum, except at a narrow interval along the attached or *mesenteric* border, where it passes off and becomes continuous with the two layers of the mesentery. The duodenum, as well as portions of the large intestine (ascending and descending colon), are only partially covered by peritoneum.

The muscular coat is arranged in two portions, each consisting of many layers of muscle fibres; the fibres of the inner portion are arranged circularly round the tube (*circular muscular coat*), while those of the outer portion run longitudinally along the intestine (*longitudinal muscular coat*). The inner or circular portion is much thicker than the outer or longitudinal portion. Between the two muscular coats there is a plexus[1] of nerve fibres, known as Auerbach's plexus. A similar plexus, but with a closer meshwork of fibres and fewer nerve cells, lies in the submucous coat (Meissner's plexus).

The *submucous coat* consists of a layer of connective tissue underlying the mucous coat, and closely connected with it. The blood-vessels ramify in this connective tissue before passing into the mucous membrane.

The *mucous coat* is bounded on the surface nearer the submucous coat by a layer of plain muscular tissue called the *muscularis mucosæ*, and its intestinal surface is lined with columnar epithelium, which covers the villi and the interspaces between them. The space between these two surfaces is occupied by fine connective tissue (*retiform tissue*), which supports the blood-vessels, nerves, lacteals,[2] and crypts of Lieberkühn, as well as the villi, into the interior of which it penetrates. In the meshes of this tissue a great number of lymph corpuscles (that is, amœboid leucocytic cells) are found.

[1] A nerve plexus is formed by a number of nerve branches uniting with one another, interchanging fibres, and then separating again. In the plexuses described above, which can only be made out with the microscope, there is formed a network of fibres, in the crossings of which ganglia of nerve cells are situated.

[2] *Vide infra*, p. 155.

A *villus* is a projection of the mucous membrane into the cavity of the intestine. It is visible to the naked eye, and the neighbouring villi are so closely set together that the inner surface has a velvety appearance. The villi are an arrangement intended both to greatly increase the absorbing area of the intestine, and also to bring the absorbing channels nearer to the absorbing cells lining the intestine. The first of these two purposes is further aided by transverse foldings of the mucous membrane as a whole; these larger folds, which are known as *valvulæ conniventes*, are shown in Fig. 80.

Each villus is covered by columnar epithelium, and within this lies fine connective tissue, of which the meshes are filled with lymph cells (lymphoid tissue). This tissue serves to support a network of capillary vessels lying just beneath the columnar cells; one or more lymphatic vessels, here called lacteals,[1] which occupy a central position in the villus (see Fig. 79); and a few strands of plain muscular fibres which run longitudinally surrounding the lacteals, and when they contract shorten the villus and expel the contents of the lacteal.[2] The blood-supply of each villus is usually obtained from one arteriole, which passes from the submucous coat through the *muscularis mucosæ* to the base of the villus. It runs up the centre of the villus parallel to the lacteal for about half way, and then breaks up into a number of capillaries, which form a plexus or network all over the villus, lying just beneath the columnar cells. The blood is collected from this network by one or two venules, which originate near the tip of the villus, and passing down to its base join a venous plexus situated in the mucous coat. From this plexus the blood is conveyed by veins to the larger venous branches in the submucous coat.

The capillary blood-vessels, which receive a great part of the absorbed food after it has been acted upon by the columnar cells, thus lie in the most advantageous position for favouring

[1] Because they are filled during fat absorption with a fine emulsion of fat, which has a milky appearance; this stream of emulsified fat can then also be seen filling the lymphatics in the mesentery, which are on this account termed lacteals.

[2] These fibres are derived from and connected with the *muscularis mucosæ*, mentioned above as underlying the mucous coat.

speedy absorption. These capillaries take up the soluble materials which have been formed by the digestion of the proteids and carbohydrates of the food; but the absorbed fat passes them, and finally enters the lymphatic capillaries or lacteals at the centre of the villus.

The proteids and carbohydrates absorbed by the blood capillaries are carried by a large vein, called the portal vein, to the liver, and are there modified in certain ways [1] before being passed on by the hepatic veins (which leave the liver) into the inferior vena cava, and so into the general circulation.

The fats pass into the central lacteal in a *very* finely emulsified condition,[2] forming a milky fluid called chyle, which is gathered up by larger lacteals lying in the mesentery, and by these carried to a number of lymphatic glands (abdominal lymphatics) lying at the attachment of the mesentery to the abdominal wall.

After passing through these glands, the chyle is carried to the thoracic duct, the main trunk of the lymphatic system (see Figs. 44, 45, pp. 66, 67), which passes up through the thorax, close to the vertebral column on the left side, to enter the venous system in the neck at the junction of two large veins of the neck (jugular vein) and shoulder (subclavian vein).

All three classes of food-stuffs after absorption thus eventually reach the general blood-stream: the proteids and carbohydrates *viâ* the portal vein, liver, and hepatic vein; the fats *viâ* the lacteals, abdominal lymphatic glands, and thoracic duct.

The absorbed food-stuffs are modified in various ways by the columnar cells after their absorption, and also in the liver on their way to join the general circulation.

The absorption by the columnar cells of substances in solution from the intestine is not by any means purely a physical process of diffusion. Many substances which are very soluble, and diffuse readily through dead or through inorganic membranes, such as the iron salts, are refused admission altogether by the living columnar intestinal cells; and other substances which diffuse very slowly, such as albu-

[1] *Vide infra*, p. 165.
[2] The so-called "molecular basis of chyle."

moses, peptones, and dextrins, are taken up greedily by these lining cells. The process of absorption is hence a selective one, and depends on the vital activity of the columnar cell. Nor does the columnar cell act like an inert membrane by allowing those substances which it *does* absorb from the intestine to pass through it unaltered into the retiform tissue underlying it, and so reach the portal circulation unchanged in nature. For each cell is a minute laboratory in which raw products are taken in at the end next the intestinal cavity, in the shape of digestion products, and finished materials, very different in character, are turned out at the fixed end to penetrate into the retiform tissue, and reach the intestinal capillaries and the lacteal. In this way all the albumose and peptone with which the columnar cell is fed from the intestine is converted into coagulable proteid again, such as is found in blood plasma; for during digestion no albumose or peptone is found in the blood of the portal vein, nor any proteid dissimilar to the ordinary proteids of blood. The carbohydrate of the intestine, in whatever form it may be absorbed by the columnar cell, is also acted upon by this cell, and changed into dextrose or grape sugar; for this is the only form of carbohydrate found during carbohydrate digestion in the portal blood. Similarly, fats are synthesized again from the fatty acids and glycerine, or from the soaps and glycerine, as which they were mainly absorbed by the lining cells, back to neutral fat. For even when fatty acids are given as food, it is as neutral fats that they are afterwards found in the thoracic duct.

The columnar cell of the intestine hence plays an important part in the process of *assimilation*—that is, in converting the products of digestion into other products, identical with those contained in the blood.

The portal vein carries the blood which has been collected from the intestinal capillaries to the liver, and in this important organ the blood undergoes various changes which affect not only the new constituents derived from the food and absorbed during the passage through the intestinal capillaries, but also those constituents which were already present in the blood as it entered the mesenteric arteries to supply these capillaries.

THE LIVER.

The liver is by far the largest gland in the body, and weighs on an average 50 to 60 ounces in the adult, being about $\frac{1}{36}$ part of the weight of the body; but it is proportionately heavier in early life, forming about $\frac{1}{18}$ part of the body weight at birth.[1] It is divided by a fissure into a right and a left lobe; of these the right is much the larger, being about four times as great, and further divided on its under and posterior surface into three secondary lobes by smaller fissures (see Fig. 81).

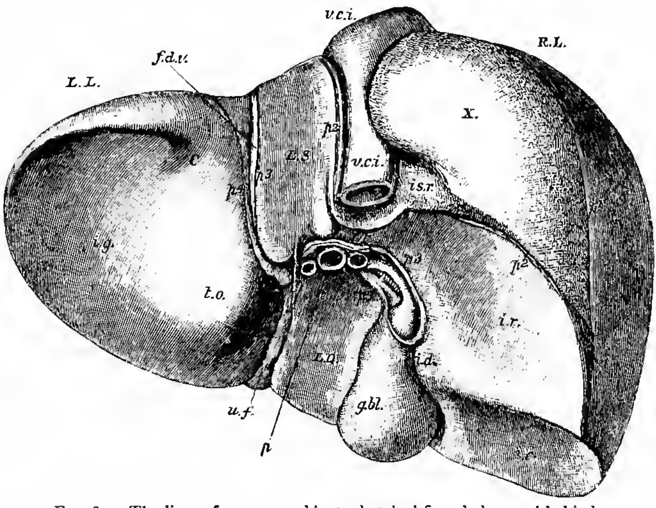


FIG. 81.—The liver of a young subject, sketched from below and behind. *R.L.*, right lobe; *L.L.*, left lobe; *L.S.*, lobe of Spigelius; *L.C.*, caudate lobe; *L.Q.*, quadrate lobe; *p*, portal fissure; *u.f.*, umbilical fissure; *g.bl.*, gall-bladder; *v.c.i.*, vena cava inferior; *i.g.*, impressions on the under surface of the left lobe correspondiog to the stomach; *C*, position of the cardia of the stomach; *X*, surface of the liver uncovered by peritoneum. (Quain's "Anatomy.")

NOTE.—The drawing has been made by Mr. Wesley from a cast prepared under the direction of Prof. His, of Leipzig.

Posteriorly there is a transverse fissure at right angles to the longitudinal fissure at which the vessels supplying the liver with blood enter. The liver differs from all other glands in the body in that its chief blood-supply is *venous*, being carried to it by the portal vein from the capillaries of the stomach, intestines,

[1] The student will find it advantageous to accompany this description with a practical examination and dissection of the liver of a sheep or pig.

pancreas, and spleen. Since the liver cells cannot be sustained by venous blood *alone*, any more than the lungs can be by the venous blood carried to them for aeration by the pulmonary arteries, a supply of arterial blood is carried to the liver by an artery (which is small compared to the size of the liver) called the *hepatic artery*, just as in the case of the lungs a supply of arterialized blood is carried by the bronchial arteries. In this way a sufficient supply of oxygen is brought to the liver cells to carry on the oxidative changes going on in them. This peculiar blood-supply of the liver, and its position as it lies interposed between the blood coming from the alimentary canal, charged with absorbed products, and the general circulation, show that an important office of the liver is to produce chemical changes in the portal blood before it passes on to the general circulation again. Some materials are taken up by the liver cells from the blood; from these substances others are formed, and these new substances are restored to the blood; it may be to perform service in another part of the body; it may be in suitable form for excretion from the body by other glands. This regulation of chemical changes by the liver in building up some substances and breaking down others is spoken of as the *metabolic*[1] *function of the liver*.

The blood derived from both the portal vein and hepatic artery is gathered up by a common system of veins after it has passed through the liver capillaries, and these veins unite into larger veins called the hepatic veins, which pour their stream into the inferior vena cava. The portal vein and hepatic artery enter the liver together at the transverse fissure (see Fig. 81) and are accompanied by the *bile duct*.[2] The three vessels branch

[1] Metabolism means the chemical alterations of the ingested food which go on in the body. Further, when substances are built up or synthesized in the body, the term *anabolism* is used to designate the process; and when substances are broken up into simpler ones, and energy set free in the process, *katabolism* is the term used.

[2] The bile duct has different names in different parts of its course: that part leading from the liver is called the *hepatic duct;* lower down this branches, and the branch going to the gall bladder is termed the *cystic duct;* while the portion of bile duct below the junction leading to the duodenum is called the *common bile duct*. The *gall bladder* is a distensible bag attached to the lower surface of the liver into which the bile flows at intervals when it is not required in the intestine, and from which it is discharged when an increased supply is required in the intestine for digestive purposes.

together as they subdivide within the liver and are surrounded by a common sheath of loose connective tissue known as the

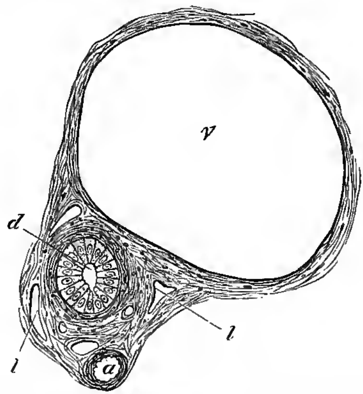


FIG. 82.—Section of a portal caoal. (E.A.S., Quain's "Anatomy.")
a, branch of hepatic artery; *v*, branch of portal vein; *d*, bile-duct; *l*, *l*, lymphatics in the areolar tissue of Glisson's capsule which incloses the vessels.

capsule of Glisson, the whole being termed a *portal canal* (see Fig. 82). The hepatic vein does not accompany these vessels, but takes a separate course through the organ.

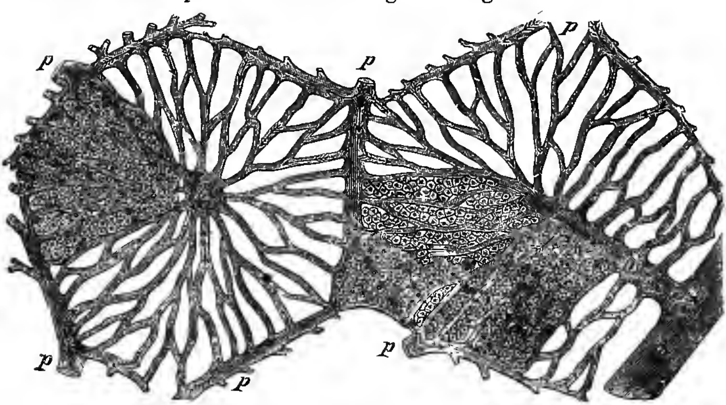


FIG. 83.—Diagrammatic representation of two hepatic lobules.
(E. A. S., Quain's "Anatomy.")

The left-hand lobule is represeoted with the intralobular vein cut across; in the right-hand one the section takes the course of the intralohular vein. *p*, *inter*lobular branches of the portal veio; *h*, *intra*lobular branches of the hepatic veins; *s*, *sub*-lobular vein; *c*, capillaries of the lobules. The arrows indicate the direction of the course of the blood. The liver-cells are only represented in one part of each lobule.

The liver substance is made up of colonies of cells, forming small polyhedral masses called lobules (see Fig. 84). The liver lobules are visible to the naked eye, and they may be distinctly seen on the fresh liver (especially in the case of pig's liver, where the lobules are more separated) as hexagonal spots, each

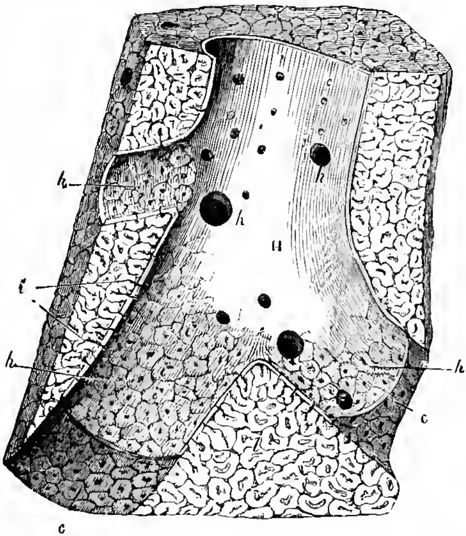


FIG. 84.—Section of a portion of liver passing longitudinally through a considerable hepatic vein, from the pig (after Kiernan). (About 5 diameters.)
H, hepatic venous trunk, against which the sides of the lobules are applied; *h*, *h*, *h*, three sublobular hepatic veins, on which the bases of the lobules rest, and through coats of which they are seen as polygonal figures; *i*, mouth of the intralobular veins, opening into the sublobular veins; *i'*, intralobular veins shown passing up the centre of some divided lobules; *c*, *c*, walls of the hepatic venous canal, with the polygonal bases of the lobules.

about the size of a pin's head. Each lobule is made up of a large number of liver cells, which, like the lobules themselves, and from a similar cause, viz. mutual pressure, are polyhedral in shape. The liver capillaries run among these cells in a manner which will be understood by referring to Fig. 83. The capillaries arise from the ultimate branches of the portal vein,[1]

[1] The hepatic artery supplies the capsule of the liver, the portal canal, and the walls of the vessels lying therein, and also has interlobular branches, which are much smaller than those of the portal vein.

which run round between the lobules, and are hence termed *inter-lobular* veins. The capillaries course inward to the centre of each lobule, where they unite to form an *intralobular* vein, and the intralobular veins, after leaving the lobules, open into the *sublobular* veins (see Fig. 84), which are branches of the hepatic vein.

The liver cells are large, and distinct in their outline; they vary in appearance according to the condition of the animal, being clear during a period of hunger, but full of granules in a well-fed animal, especially a few hours after a meal. Some of the granules consist of a reserve form of carbohydrate termed *glycogen*, which the liver cells form from any excess of sugar which may be present in the blood as it comes to the liver. These granules stain dark brown with iodine. Others of the granules are fat globules; for the liver cells also act as a temporary storehouse for fats.

The bile ducts, which collect the bile and carry it away from the liver, commence between the hepatic cells as fine passages, or *canaliculi*. The bile canaliculi open into the minute bile ducts at the circumference of the lobule, and these unite with one another to form larger ducts

The Bile.

Bile is a thick mucous fluid varying in colour from brown or orange yellow to olive green. The viscidity of bile is due to mucin, which is added to it in the gall-bladder. The mucin may be removed as a stringy precipitate by the addition of a few drops of acetic acid, and the filtrate then forms a mobile fluid. Bile contains, in addition to mucin, the following constituents in solution in water: viz. bile salts, bile pigments, small quantities of fats, lecithin, cholestearin, and inorganic salts.

The *bile salts* are sodium salts of two complex organic acids called *glycocholic* and *taurocholic* acid. These are compounds of an acid called *cholalic acid* with an amido-acid. In the case of glycocholic acid the amido-acid is *glycocoll* (amido-acetic acid), and in the case of taurocholic acid it is *taurine* (amido-oxyethyl sulphonic acid). An amido-acid is one in which an

atom of hydrogen has been replaced by a molecule of ammonia, and hence both glycocoll and taurine contain nitrogen; taurine further contains sulphur. The presence of nitrogen and sulphur in these bodies points out that they are products of the decomposition (katabolism) of proteids, and hence that the liver in which they are formed has an important influence on proteid metabolism.

The bile salts have an important function in rendering cholestearin and lecithin soluble in the bile, and so providing a means for the removal of these substances from the body. Cholestearin and lecithin are decomposition products of the nervous tissues; they are insoluble in water, but by the agency of the bile salts are rendered soluble in the bile, and so can easily be conveyed to the intestine in solution and removed from the body. As further evidence of this use of the bile salts there is the fact that they are re-absorbed in great part from the intestine and are again excreted by the liver, thus completing what is known as *the circulation of the bile.* A similar purpose is served by the bile salts in the absorption of fatty acids and soaps from the intestine, for the solubility of these is much increased by the presence of bile salts.

The bile salts have an intensely bitter taste, and may further be recognized in solution by the intense violet they give when warmed in a thin film with a drop of strong sulphuric acid and a crystal of cane sugar (*Pettenkofer's test*).

The bile owes its colour to the bile pigments. Two pigments are usually present in bile, in varying quantity, called bilirubin and biliverdin. Bilirubin has a golden yellow colour, and biliverdin a deep olive green, so that the varying colour of bile is due to the different proportions in which different samples contain the two pigments. The two pigments are closely related in chemical composition, biliverdin being an oxidized derivative of bilirubin. When yellow-coloured bile is electrolyzed it turns green round the positive pole on account of oxidation taking place there; the same effect is obtained if it be made more strongly alkaline and exposed to the oxygen of the air in thin layers; or if it be exposed to a gentle oxidizing agent such as iodine solution. When a stronger

oxidizing agent is employed, such as strong nitric acid, the oxidation proceeds further, and after biliverdin a blue coloured body is formed (*bilicyanin*), which is finally replaced by a dark brown substance called *choletelin.*

On account of these successive oxidations, when a thin film of bile is spread out on a porcelain vessel or on a piece of filter-paper, and a drop of strong fuming nitric acid added in the centre, a change of colours is observed—first green, then blue, and finally dark brown. These colours form rings round the central spot, the green being farthest removed from the acid. These colour changes constitute *Gmelin's test for the bile pigments.*

Bilirubin is the most reduced of the naturally occurring bile pigments, but when it is acted upon by a reducing agent (such as sodium amalgam) it yields an artificial compound called *hydrobilirubin.* The importance of this hydrobilirubin lies in the fact that it has also been obtained by acting with reducing agents on hæmatin, a decomposition product of hæmoglobin, and hence shows that the bile pigments are products of a downward metabolism of hæmoglobin taking place in the liver. This relationship of the bile pigments to hæmoglobin is further shown by the fact that in old blood-clots formed abnormally in the blood, the hæmoglobin of the red blood corpuscles is converted into a body called *hæmatoidin*, which has been shown to be identical with bilirubin. The bile pigments are not present in large amount by weight in the bile, and but for this connection with hæmoglobin would not have any great physiological importance; they are not absorbed again like the bile salts, but pass out with the fæces. In the passage along the intestine they become completely reduced, and are present in the fæces as hydrobilirubin, which when it was first discovered here was termed *stercobilin.*

Bile has a strongly alkaline reaction, due to the sodium carbonate and phosphate which it contains; sodium chloride is the only other inorganic salt which it contains in appreciable quantity.

METABOLISM IN THE LIVER.

We have next to consider the chemical action of the liver on the blood flowing through it. The function of the liver is here twofold in character; in the first place its cells act as a temporary storehouse for certain classes of food-stuff, and in the second, the final stages in the degradation or katabolism of other food-stuffs take place here, yielding products for excretion from the blood-stream, either by the liver itself or by the kidneys.

There is no evidence that the liver acts as a temporary storehouse for proteids; such evidence would be most difficult to obtain, because the protoplasm of the liver cells is largely made up of proteid, and hence a variation in the amount of proteid would be hard to estimate.[1] On the other hand, there is clear evidence that the liver cells are concerned in the katabolism of proteid. This is shown, not only by the identity of the bile pigments, as stated above, with the degradation products of hæmoglobin, but by the fact that *urea*, as which practically all the nitrogen of the proteid of the food is removed from the body, is formed in the liver.

Urea is excreted by the kidneys in the urine, and it might be supposed at first sight that urea was formed by the kidney cells, but this has been shown not to be the case. When the kidneys of an animal are removed, the production of urea in its body does not cease; on the other hand, the percentage of urea in the blood increases, and the animal dies from poisoning of its blood with urea. This shows that the kidneys do not form urea, but merely remove it from the blood passing through them. If the liver, instead of the kidneys, be removed, there is no accumulation of urea in the blood, but instead certain ammonium salts make their appearance. Further, if the blood from the portal vein of a recently fed animal be

[1] There never takes place in the body in general so much storage of proteid as there does of carbohydrate or fat; this is shown by the fact that when the proteid in the food is increased, the nitrogen excreted as urea is correspondingly increased. Under such conditions, the excess of proteid is not used to form tissue, but as a source of energy, and a saver of carbohydrate and fat.

passed through the excised liver of an animal which has not been recently fed before death, it is found that the percentage of urea in the blood increases. Again, if an ammonium salt be added to whipped blood, which is then perfused through a liver just excised from an animal, it is found that a great deal of the ammonia disappears and is replaced by urea. It is clear from these experiments that the liver cells produce urea, and that they probably manufacture it from ammonium salts circulating in the blood.[1]

It was at one time believed that the amount of urea so formed represented the tissue waste, and hence that the amount of urea formed and excreted must vary directly as the amount of work done by the tissues. This is not, however, the case, the amount of urea excreted is directly proportional to the amount of proteid food consumed. Of course, increased work by the tissues increases the amount of wear and tear on the protoplasm of their cells, and hence increases the amount of tissue repair required, but this amount is insignificant compared with the amount of proteid or other foodstuff broken down to supply energy for muscular contraction. Carbohydrate and fat can replace proteid as sources of muscular energy at the expense of chemical energy. Hence if the amount of carbohydrate food given be sufficient, and there be no increase of proteid food, increased muscular work can be done with little or no increase in the formation of urea, *i.e.* without increased proteid consumption. There is, however, increased production of carbon-dioxide and water, which indicates combustion of carbohydrate to supply the necessary energy for the muscular work done. It follows that the relative amounts of urea, of carbon-dioxide, and of water formed, depend on the relative amounts of carbohydrate, of fat, and of proteid taken as food, and upon these only.

While it is improbable that the liver acts to any appreciable extent as a storehouse for proteids, there is no doubt whatever that it has an important function in so acting with regard to carbohydrates.

When an animal is liberally fed on a carbohydrate food,[2] the cells of its liver soon become charged with granules of a carbohydrate belonging to the amylose (polysaccharide) group,

[1] The most probable salt is ammonium lactate, for lactic acid is formed during muscular contraction, and it is also in the muscles that most oxidation of proteid takes place when proteid food is liberally given ; the ammonium lactate so formed passes to the liver, and, in some unknown way, the liver cells prepare urea from it, which is restored to the blood, to be again removed in the kidneys and passed out in the urine.

[2] Such as rice, potatoes, or carrots.

and known as *glycogen*, or animal starch. The glycogen granules can be stained a deep brown when sections of the liver are treated with tincture of iodine; also the glycogen itself can be prepared in quantity from such a liver, and its chemical properties tested.[1] After death it quickly changes into grape sugar; a similar change also takes place during the life of the animal, if the carbohydrate supply be stopped or greatly diminished. Glycogen, besides being found in the liver, is also found in lesser quantity in the muscles, but disappears after the muscles have been fatigued by over-work, being then used up to furnish a supply of energy. During a period of rest, there is a new formation of glycogen, which again becomes expended in the next period of activity.

Storage of glycogen in the liver cells takes place when the percentage of dextrose in the portal blood coming to them exceeds a certain limit; as, for example, during the digestion of a meal containing carbohydrate. On the other hand, when the amount of dextrose in the portal vein falls below a certain limit (about 2 parts per 1000), there is an insufficient amount of circulating carbohydrate to supply the necessary energy to the tissues (especially to the muscles), and accordingly a certain amount of the carbohydrate previously stored in the liver cells in the form of glycogen is reconverted into dextrose, and discharged into the blood-stream[2] to keep the percentage of circulating carbohydrate up to the normal mark. These statements are supported by the experimental observations that, during digestion of carbohydrate the percentage of sugar (dextrose) in the portal vein (going to the liver) is greater than that in the hepatic vein (leaving the liver); while, during a period when no digestion is taking place, the situation is reversed, and there is more sugar in the hepatic blood than in the portal blood. Thus the liver cells act as governors on the amount of soluble carbohydrate in the form of dextrose circulating in the blood. This is an important function, for, on the one hand, excess of dextrose in the circulation acts injuriously on the tissues, and the excess is treated as a foreign substance, and

[1] See Appendix.
[2] Not directly, of course, but by the medium of the intervening lymph.

excreted by the kidneys, giving rise to a great waste of the carbohydrate food; while, on the other hand, an insufficient amount of circulating carbohydrate leads to debility of the muscular tissues, and to morbid changes in the cells of the tissues generally.

This storing of carbohydrate is spoken of as *the glycogenic function of the liver.*

This function may be disturbed by certain artificial means, such as removal of the entire pancreas; puncture of a portion of the brain, known as the fourth ventricle; administration of certain drugs, such as phloridzin, or curare. When so disturbed, the liver cells do not behave any longer in a normal fashion; there appears an excess of sugar in the blood, which is passed out of the body in the urine (*glycosuria, diabetes*), and wasting of the tissues is the result. Under such circumstances, complete stoppage of carbohydrate in the food, although it diminishes the amount of sugar excreted, does not entirely stop it; for the liver cells continue to form an excessive amount of carbohydrate from the proteid of the food, which they are able to act upon and convert in part into carbohydrate.

The liver cells are also capable of acting as a temporary storehouse for fats; for, after a meal rich in fat, the cells of the liver are found to contain fat granules.[1] But such a storage of fat in the liver is, under normal conditions, very transitory, and prolonged storage takes place chiefly in the connective tissue of certain regions of the body, such as, in the subcutaneous connective tissue generally, and more especially in that of the abdomen; in the connective tissue lying under the peritoneum in which the kidneys are embedded; in the great omentum; and upon the muscular tissue of the heart underneath the pericardium. In these parts the cells of the connective tissue become loaded with fat, which first appears in the cells as minute granules. These granules become larger and coalesce until the cell becomes mainly a globule of fat surrounded by a membrane with only the nucleus and a trace of the cell protoplasm remaining. Connective tissue so altered to store up fat is termed *adipose tissue;* it becomes arranged in lobules, each of which is copiously supplied with blood by a small arteriole, from which capillaries are formed surrounding

[1] The granules are shown to be fat by their staining black with osmic acid, and by their solubility in ether or xylol.

the fat cells. The fat cells probably synthesize a great deal of their fat from carbohydrate instead of from fat, and it is also probable that when there is a scarcity of fatty or carbohydrate food, and the storage of fat comes into use, that part of it is returned, by the aid of the cells, to the blood as carbohydrate.

In the animal organism it is certain that proteid cannot be formed from carbohydrate, or fat, and nitrogenous inorganic salts.[1] Such a synthesis can only be carried out by plant cells, and hence upon plant proteid directly (herbivora) or indirectly (carnivora) animal life is dependant for its indispensable proteid supply. With this one reservation, however, it may be stated that the three classes of food-stuff can replace one another, and can be converted to a certain extent into one another in the course of the complex chemical changes which go on in the cells of an animal's body.

Thus, proteid can be used up by the cells, and either carbohydrate or fat produced in its stead. If the liver of an animal be freed of glycogen by administration of a drug (such as phloridzin) which causes the glycogen to be discharged as sugar in the urine, and then, the administration of the drug being stopped, is kept on a purely proteid diet for some time and finally killed, it is found, post-mortem, that the liver cells contain a fair amount of glycogen. Again, in cases of diabetes, as stated above, the excretion of sugar in the urine cannot be completely stopped by placing the patient on a diet from which carbohydrates are carefully excluded, or even by feeding on proteid alone.

Similarly, if fat be excluded from the food, and a purely proteid diet be given to an animal, in a short time the liver cells become free from fat. If, at this stage, phosphorus be administered to the animal, and it be killed after some time, it will be found that the liver cells are loaded with fat. This production of fat is due to "fatty degeneration" of the proteid constituents of the protoplasm of the cells under the influence of the drug. Such an over-production of fat from proteid is merely an exaggeration of a normal process, and it is probable that when an excess of proteid food is taken, above that

[1] This is shown by the fact that animals cannot live without proteid food.

required for the immediate wants of the animal, that a portion of the excess is in part converted by chemical changes brought about by cell protoplasm into carbohydrate or fat.

There is also abundant evidence that carbohydrate can be converted into fat and stored as such in the adipose tissue of the body. In fact, carbohydrate food is a more efficient fat producer than are the fats themselves. This has been shown by experiments on the fattening of swine. In one case carbohydrate food was given, and in the other a corresponding weight of fat, and it was found that the animals fed on carbohydrate accumulated much more fat than those fed on fat. Further, on feeding young animals on a food rich in carbohydrates, and containing as little fat as possible, it is found that the amount of fat stored up in the body is much greater than the total amount of fat found by analysis as having been given in the food.

So marked is this formation of fat from carbohydrate that it was at one time thought that none of the fat taken in the food could be directly stored in the body without alteration. It was supposed that all the fat of the food served as an immediate source of energy, for muscular work and for heat production (especially the latter); that all the fat found in the adipose tissue was synthetically formed from other material, chiefly carbohydrate, by the activity of the cell protoplasm; and that none could be directly laid down without change from the fat of the food. This view was supported by the fact that the fat of each species of animal has a fairly definite chemical composition and melting-point, due to the admixture of the several fats composing it in definite proportions. Thus, pig's lard has a lower melting-point than the fat of beef suet, and this again melts more easily than the fat of mutton suet.[1] But it has been shown that, *under certain circumstances*, the fat of the food may become directly incorporated as tissue fat. This has been

[1] These fats are mixtures of three fats, called olein, palmitin, and stearin; of these three, olein is fluid at ordinary atmospheric temperatures, and stearin is solid at even several degrees above body temperature. The melting-point of the mixture varies with the proportion of each present; in lard there is a large amount of olein, in mutton fat very little, and hence lard is fluid at body temperature, while mutton fat is solid.

shown in two ways. One consists in feeding an animal for a long time on a form of fat containing a peculiar constituent which can be easily recognized again by chemical methods, and which is not contained in the ordinary fats of the animal's body.[1] Afterwards, when the animal has been killed, this peculiar constituent has been found in the fat of its body. The other method consists in keeping the animal on a low diet for some time, until the storage of fat in its body has become greatly reduced, and then feeding for a considerable time with fat from another species of animal. It is found that when a dog is so treated, and fed on mutton suet, that the fat of its body has a much higher melting-point than is normal for the fat of the dog—approximating, in fact, to that of mutton fat.

In order to obtain a successful result by either of these methods, it is necessary, however, that the stock of the animal's own fat should be low, that it should be allowed to eat no other kind of fat, and that carbohydrates should also be excluded from the food. These are somewhat abnormal conditions, and hence, although the experiments demonstrate that the fat of the food may be directly built up into tissue fat under certain conditions, they do not show that such direct deposition takes place to any marked extent under *normal* conditions. In fact, it is probable that under usual conditions the greater part of the fat of the body is synthesized by the cells of the adipose tissue from carbohydrate.

To sum up, then, all three classes of food-stuffs are used in the body as sources of energy. They supply the cells of the various tissues with nutriment, and undergo chemical changes in these cells in the course of which their chemical energy becomes diminished, being converted into cell activity and in the end into heat, which serves to keep up the temperature of the body. Finally, after passing through intermediate stages, they are resolved into bodies of much simpler chemical

[1] Fats which have been used for this purpose are linseed oil, which contains erucic acid; and spermaceti, which contain cetyl alcohol; these substances are not present in the ordinary fats of the food and of the body, and their presence in the body-fat, after ingestion, serves as a signal that the fat of which they formed a constituent has not been broken up to any great extent in the body.

composition,[1] and possessed of but little chemical energy, which are excreted from the body chiefly by the lungs and kidneys. In yielding to the body a store of energy the different food-stuffs can replace one another, but a certain amount of proteid is *in animal life* indispensable, because this form of food alone can repair the waste of protoplasm going on in the tissues.

[1] The chief of these are water and carbon dioxide, in the case of the fats and carbohydrates; and in addition to these urea, with traces of other nitrogenous bodies, in the case of the proteids.

CHAPTER VIII.

RESPIRATION.

In the processes of oxidation which are continuously going on in the tissues, oxygen is used up and carbon dioxide formed. The oxygen is carried *to* the tissues, and the carbon dioxide *from* the tissues by the blood. Hence the blood, in passing through the systemic capillaries, becomes poorer in oxygen and richer in carbon dioxide. In order that its composition may remain unchanged it is obvious that in some other part of the circuit it must take up oxygen and give off carbon dioxide. This change takes place in the capillaries of the lung, in its passage through which the blood takes up oxygen from the air of the lungs and gives up to it a certain amount of carbon dioxide. In passing through the systemic capillaries the arterial blood becomes venous; in the passage through the pulmonary capillaries the venous blood becomes arterial.[1]

That a rapid exchange of gases may take place in the lungs two conditions are necessary: first, that there should be a large surface of blood exposed to the action of the air in the lungs, and that this large surface of blood should be as little as possible separated by tissue from the air, so that rapid diffusion may take place; and, secondly, that there should be some means of quickly changing the air to which the blood is exposed, so that it may not become charged with that gaseous product (carbon dioxide) which it is essential should be removed from the blood, nor poor in that constituent (oxygen) which it is necessary that it should furnish to the blood.

[1] Hence the pulmonary artery contains venous blood, and the pulmonary vein arterial blood.

Both these conditions are fulfilled in the respiratory apparatus, in which a large surface of capillaries is constantly

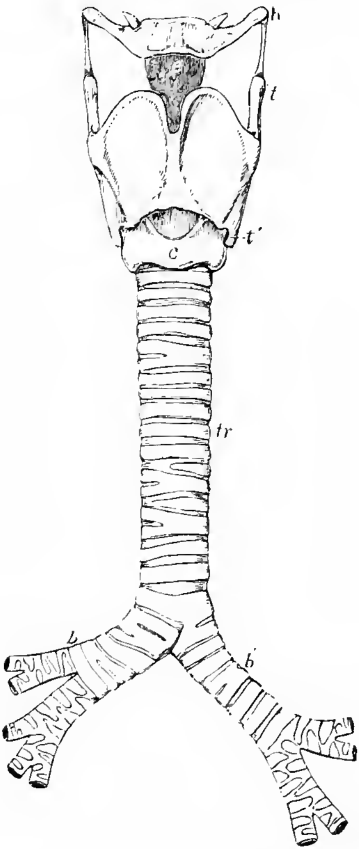


FIG. 85.—The trachea. Front.
h, hyoid bone; *tt'*, thyroid cartilage; *c*, cricoid; *e*, epiglottis; *tr*, trachea; *b* and *b'*, bronchi. (Allen Thomson.)

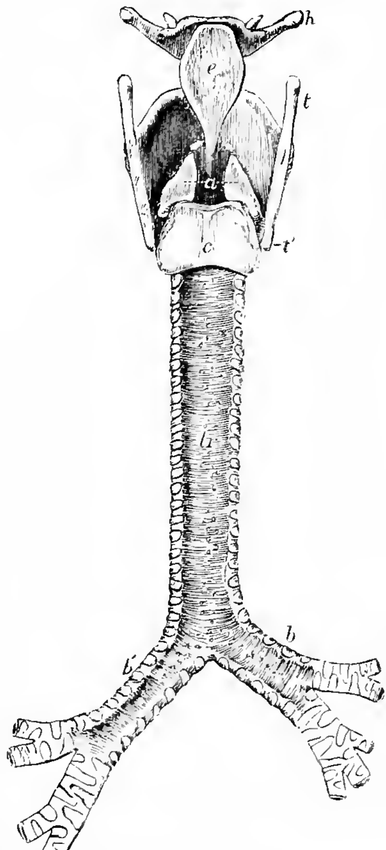


FIG. 86.—The trachea. Back.
a, arytenoid cartilages; *h*, hyoid bone; *tt'*, thyroid cartilage; *c*, cricoid; *e*, epiglottis; *tr*, trachea; *b* and *b'*, bronchi. (Allen Thomson.)

exposed to air, which is continually renewed by the respiratory movements and gaseous diffusion.

The manner in which the air is alternately pumped into and

out of the lungs, on account of the lungs being compelled to follow passively the alterations in volume of the air-tight thorax, has already been explained (see p. 32); it remains to describe the structure of the respiratory system, and the manner in which this structure facilitates an exchange of gases between blood and air.

The respiratory system communicates with the alimentary canal at the front and lower part of the pharynx, where the windpipe or air-passage begins in a cartilaginous box called the *larynx*, which is the organ of voice. To the lower

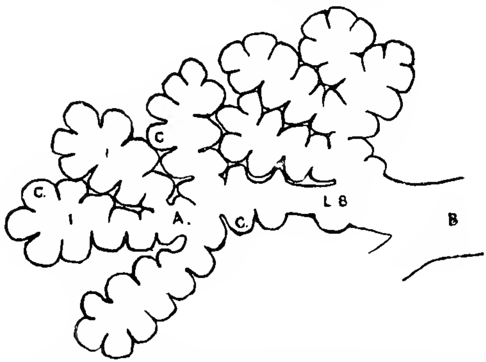


Fig. 87.—Diagrammatic representation of the ending of a bronchial tube in sacculated infundibula. (E. A. S., Quain's "Anatomy.")

B, terminal bronchus; LB, lobular bronchiole; A, atrium; I, infundibulum; C, air-cells, or alveoli.

end of the larynx the *trachea* is attached (see Figs. 85 and 86); this lies in front of the œsophagus in the neck, and enters the thorax, where it soon bifurcates into two branches termed the *bronchi*, which pass one to each lung. The bronchus enters the lung at the root, and within the lung branches and branches again, in a tree-like fashion, giving rise to the *bronchioles*, which become smaller in section at each successive branching. The ultimate branches are known as the *bronchial tubes*, each of which ends in an expanded sac-like structure known as the *infundibulum.* The walls of each infundibulum are lined by honeycombed recesses known as the *air cells*, or *alveoli.* It is in these minute air-cells, or alveoli, lining the walls of the

infundibula that the real work of gaseous exchange between the air filling the infundibula (*alveolar air*) and the blood in the pulmonary capillaries takes place. It will be readily understood that by this arrangement a very large extent of surface is obtained. By far the greater part of the volume of a moderately distended lung is made up of these infundibula lined with alveoli, so that the total surface so exposed for the aeration of the blood amounts to many square yards.[1]

The trachea, bronchi, and bronchioles are held open, so as to always allow free passage to the air in and out, by incomplete hoops or rings of cartilage situated circularly in the substance of their walls. The cartilages are connected by fibres of elastic tissue running lengthwise along the air-passages, internal to the cartilages, and between them. Externally there is a coat of connective tissue, and internally there is a thick mucous membrane. The *mucous membrane* is lined throughout by *ciliated* epithelium[2] from the upper part of the trachea to the termination of the bronchioles at the commencement of the infundibula (see Fig. 88). Amongst the ciliated cells there are situated a large number of goblet cells which secrete mucus to moisten the ciliated mucous membrane. The cilia move in such a way as to move any foreign particles which may have been drawn in with the air (as well as the mucus moistening them) upwards towards the pharynx and so away from the lungs.

In this manner, the lungs are greatly protected from being choked with dust and floating particles of all kinds drawn in with the air. Still, the protection is not quite complete, and some of the finest particles float in the air within the air-passages, without touching the walls and so adhering to them, quite down to the alveoli, where there is no ciliated lining. Such particles become absorbed, and in the case of old persons who have lived many years in large cities, the lungs after death are found to be quite black from having become in this manner impregnated with fine coal dust.[3]

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[1] The alveolar area has been estimated at 200 square metres (over 240 square yards).

[2] The greater part of the larynx (except over the true vocal cords and over the epiglottis) is also lined with ciliated epithelium.

[3] A portion of this foreign matter is taken up by the numerous lymphatics of the lungs and carried to a group of lymphatic glands situated at the root of each lung where it becomes deposited, so that after some

The epithelial cells rest on a membrane (*basement membrane*) which separates them from the rest of the mucous coat under-

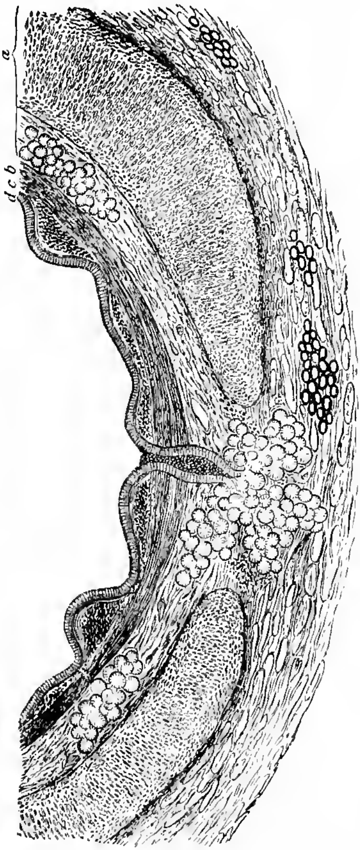

FIG. 88.—Portion of a transverse section of a bronchial tube, human, 6 mm. in diameter. (F. E. Schultze.) (Magnified 30 diameters.)

a, cartilage and fibrous layer with mucous glands, and, in the outer part, a little fat; in the middle, the duct of a gland opens on the inner surface of the tube; *b*, annular layer of involuntary muscular fibres; *c*, elastic layer, the elastic fibres in bundles which are seen cut across; *d*, columnar ciliated epithelium.

lying them; this consists of lymphoid tissue (that is, connective tissue in which the meshes are filled by lymph corpuscles)

years these glands become quite gritty; in fact, in old persons who have lived in cities, more like pieces of coke than glands. This deposition of carbon is, however, quite innocuous, and is not sufficient to interfere materially with the functions of the lungs.

and supports numerous small blood and lymphatic vessels which supply the surrounding tissue. In this tissue, as well as deeper down near the cartilaginous rings, in what is termed the *sub-mucous layer*, lie numerous mucous glands (see Fig. 88) which open on the ciliated surface and assist the goblet cells in providing the moistening mucous fluid. An annular ring of muscle fibres of the plain or involuntary variety is also present, underlying the mucous coat, and most strongly developed opposite that part where the cartilage is incomplete. In the trachea and bronchi, the cartilages are all incomplete at the same part, viz. at the back, and here there is a strong band of involuntary muscle fibres arranged horizontally; while in the bronchioles the incomplete portions of the rings do not correspond in situation. The advantage of the incompleteness of the cartilaginous rings at the back of the trachea is obvious; here the trachea lies against the œsophagus which is usually collapsed; but when a bolus of food passes along, the œsophagus becomes distended, and the absence of the cartilages in front where the trachea lies in contact with it allows the necessary distension to take place more freely.

In the smaller branches of the bronchioles as they near the infundibula the cartilage disappears, and a complete layer of plain muscular fibres surrounds the tube, the whole being enclosed by a layer of loose fibrous tissue. The mucous membrane lying internal to the muscular layer is constituted much as in the larger tubes, but there is less connective tissue. In the stratum of the mucous membrane underlying the epithelium much elastic tissue is present, of which the fibres are chiefly arranged parallel to the length of the tube. As the bronchial tube finally expands into an infundibulum, the wall thins out, and the several layers above described disappear; at the same time the character of the lining epithelium alters, and the ciliated cells are chiefly replaced by large irregularly shaped flattened cells, which form an exceedingly thin delicate membrane covering the alveolus (see Fig. 89). At some places this flattened epithelial layer is replaced by cubical epithelial cells (see Fig. 89), but by far the greater part of the alveolar surface is covered by the flattened scales,

which form the only covering (with the exception of the equally thin walls of the capillaries themselves) separating the blood in the pulmonary capillaries from the air in the alveoli.

These pulmonary capillaries are arranged in a close meshwork over the concave surface of each alveolus, just beneath the thin pavement epithelium. The pulmonary artery and its larger subdivisions follow the branchings of the bronchus

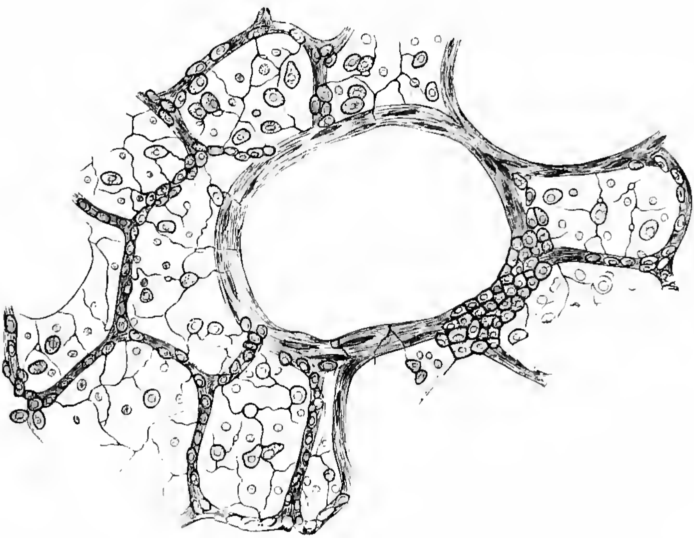

FIG. 89.—Section of part of cat's lung, stained with nitrate of silver. (Klein.) (Highly magnified.)

The small granular and the large flattened cells of the alveoli are shown. In the middle is a section of a lobular bronchial tube, with a patch of the granular pavement-epithelium cells on one side.

at first, but the finer branches, in the end, leaving the smaller bronchioles, branch independently, and finally small arterioles are given off from these which run round the margins of the alveoli and give off capillaries all the way round. The capillaries unite to form minute veins which collect the blood into larger venous radicles lying in the connective tissue between the infundibula, and these unite again to form still larger vessels, which after pursuing an independent course for

some time finally run along the course of the bronchioles, and eventually form the two pulmonary veins which leave the root of each lung and carry the oxygenated blood back to the left auricle.

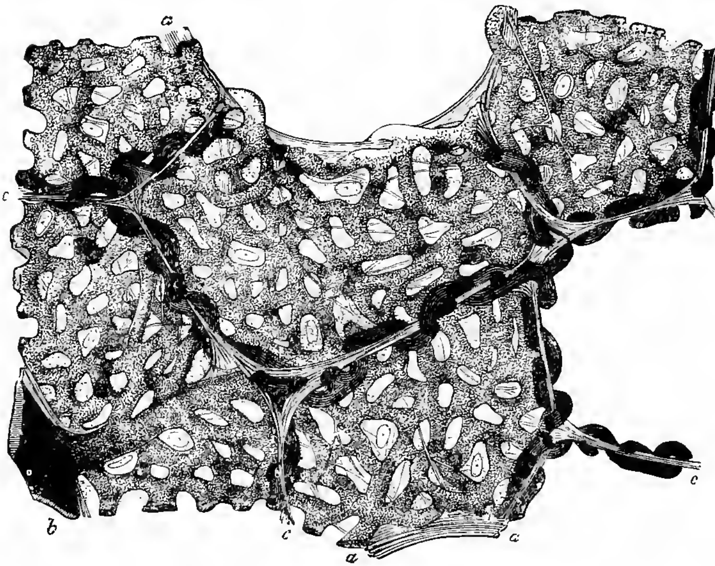

FIG. 90.—Section of injected lung, including several contiguous alveoli. (F. E. Schultze.) (Highly magnified.)

a, a, free edges of alveoli; *c, c,* partitions between neighbouring alveoli, seen in section; *b,* small arterial branch giving off capillaries to the alveoli. The looping of the vessels to either side of the partitions is well exhibited. Between the capillaries is seen the homogeneous alveolar wall with nuclei of connective-tissue corpuscles and elastic fibres.

The lungs are never completely emptied of air, even when the greatest effort to breathe out[1] is made, for after the greatest possible expiratory effort the lungs still contain, on the average, in the adult, 1000 cubic centimetres (about 60 cubic inches) of air; this air is called the *residual air.* The amount of air which can be breathed out after an ordinary expiration down

[1] Breathing out is termed *expiration*, and breathing in is termed *inspiration*.

to the greatest possible forced expiration is termed the *supplemental* or *reserve air*, and it measures about 1500 cubic centimetres. These two fractions, viz. residual and supplemental air, together make up what is often called the *stationary* air, because, in quiet breathing, it is the amount retained all the time in the lungs. The amount of air normally passing in and out of the lungs in quiet breathing is called the *tidal* air, and measures on the average about 300 cubic centimetres, although it varies so in different individuals that the average amount possesses little importance. Between the amount of air in the lungs at the end of an ordinary inspiration and the amount at the end of the *greatest possible inspiration* there is a difference of about 1700 cubic centimetres, and this fraction is termed the *complemental* air.

The maximum amount of air which can be taken into or breathed out from the lungs by a single effort, obviously includes the fractions of *reserve*, *tidal*, and *complemental* air; this amount is known as the *vital capacity*, and measures 3000 to 4000 cubic centimetres.

In quiet breathing, the air enters the nostrils and passes along the nasal passages to enter the pharynx at the posterior openings of these passages—*the posterior nares*. It passes through the pharynx, enters the larynx at the opening of this from the pharynx, called the *glottis*, and passes down the trachea into the bronchi. The amount of air taken in at each ordinary inspiration is quite insufficient to reach the alveoli, and is merely enough to fill the nasal passages, pharynx, larynx, trachea, bronchi, and larger bronchioles. The rest of the work, whereby the alveolar air becomes changed in composition, is effected by gaseous diffusion, and so perfect and rapid is this that the alveolar air differs but little in composition from expired air.

The air in its passage through the air-passages is brought in contact with the warm and moist surface of the mucous membrane lining the nasal cavities, and is here both warmed almost to the temperature of the body, and nearly saturated with water vapour. These processes are completed before the air leaves the body, so that the expired air has the temperature

of the body, and is completely saturated with aqueous vapour at that temperature.[1]

The chemical composition of the air is also altered in the process of respiration. Atmospheric air contains in round

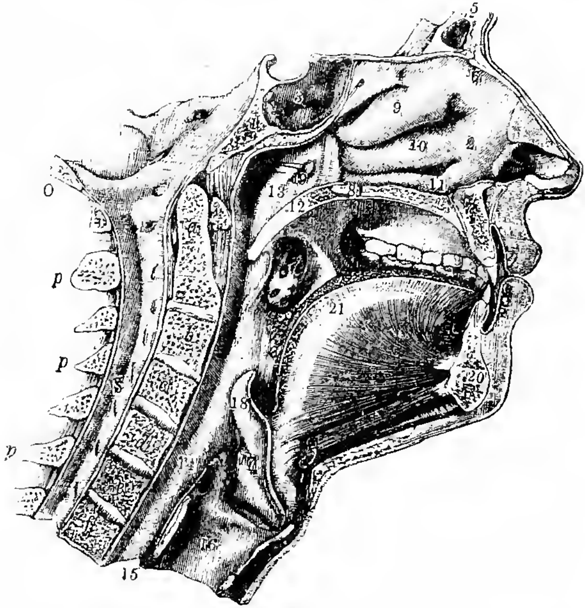

FIG. 91.—Medial section of the face and neck.

1, sphenoid bone; 2, nasal cavity; 3, brain cavity; 4, ethmoid bone; 5, frontal bone; 6, nasal bone; 7, superior maxillary bone; 8, palatal bone; 9, superior turbinated bone; 10, middle turbinated bone; 11, inferior turbinated bone; 12, soft palate; 13, upper part of pharynx; 14, lower part of pharynx; 15, œsophagus; 16, larynx; 17, glottis; 18, epiglottis; 19, opening of Eustachian tube; 20, inferior maxillary bone; 21, tongue; 22, tonsil; *a* to *f*, bodies of cervical vertebræ; *s*, spinal cord; *p*, processes of cervical vertebræ; *o*, portion of occipital bone.

numbers, in 100 parts by volume, about 79 parts of nitrogen, 21 of oxygen, and but 3 parts in 10,000 (in good air) of carbon dioxide, while expired air contains about 4 per cent. of carbon dioxide, only 16 per cent. of oxygen, and the balance of nitrogen. The presence of carbon dioxide in expired air can

[1] See p. 192.

easily be shown by breathing out through lime water, when a heavy white precipitate of calcium carbonate is obtained. By somewhat more delicate analysis, the diminution in the percentage of oxygen may be detected; this diminution in the oxygen is always in excess of the carbon dioxide formed, and the volume of the expired air is correspondingly less than that of the inspired air, showing that the oxygen which is missing has not gone to form a gaseous compound. As already explained, this oxygen has been utilized in combining with the excess of hydrogen in the fats and proteids of the food during the combustion of these bodies in the tissues.

The changes in the air in the process of respiration, then, are these—

(*a*) *The air is warmed* (or cooled) *to the temperature of the body.*

(*b*) *The air is saturated with aqueous vapour at that temperature.*

(*c*) *The air is changed in chemical composition, about* 5 *per cent., roughly, of oxygen disappearing and* 4 *per cent. of carbon dioxide appearing.*

The chemical changes which give rise to the alteration in chemical composition of respired air do not *take place*, as was originally thought, in the lungs, but *in the tissues.* The process is really one of slow combustion, or chemical oxidation, going on in the cells of the tissues, and chiefly in the muscular tissues, and the lungs are a ventilating agency, taking in stores of oxygen and removing the carbon dioxide formed.

That the oxidation does not take place in the lungs is shown by the fact that the arterialized blood leaving the lungs contains a much higher percentage of oxygen than the venous blood coming to the lungs, and at the same time a much less percentage of carbon dioxide,[1] thus showing that the blood has

[1] Although the above statement is true, still both venous and arterial blood contain more carbon dioxide than oxygen. Blood contains in round numbers 60 per cent. of gas, of which, in arterial blood, about 40 volumes are carbon dioxide, and 20 volumes oxygen, while in venous blood about 46 volumes are carbon dioxide, and 8 to 12 volumes are oxygen. Both arterial and venous blood contain about 1 per cent. of nitrogen, which is simply dissolved in the plasma.

given up carbon dioxide in the lungs and taken up a supply of oxygen for use somewhere else in the circuit. That the oxidation does not take place in the blood is shown by the fact that the composition of the contained gases does not change until the capillaries have been reached, and that it does take place in the tissues is shown by the fact that, in passing through the capillaries of the tissues, all the decrease in oxygen and increase in carbon dioxide occurs.

We have next to consider in what way oxygen is taken up in the passage through the lungs, and carbon dioxide given off; why the reverse change takes place in the tissues, and how the oxygen and carbon dioxide are held in the blood.

The oxygen and carbon dioxide are held dissolved in the blood partially by physical and partially by chemical means—that is to say, partially in solution and partially in chemical combinations.

The amount of oxygen which the blood plasma is capable of holding in simple solution is very small, and is only a small fraction of that which is taken up by the blood; by far the greater part is held in a loose state of chemical combination with the *hæmoglobin* of the red corpuscles, forming an unstable compound, called *oxy*-hæmoglobin. When the oxygen pressure in the plasma is high, as is the case when the blood is in contact with air containing a fair percentage of oxygen (as, for example, in the lungs), then the hæmoglobin takes up oxygen from the plasma until it becomes saturated with it. On the other hand, when the oxygen pressure in the plasma is low, the compound of hæmoglobin becomes broken up,[1] and the oxygen is given out to the plasma.

This taking up or giving out of oxygen by the hæmoglobin is *not* a very gradual process, *the amount of oxygen taken up does not increase proportionately to the pressure of oxygen, but at a certain pressure of oxygen the gas is taken up rapidly, and when the pressure is only slightly higher, the hæmoglobin becomes almost completely saturated, and takes up very little more even if the oxygen pressure be greatly increased.* The pressure at

[1] The oxy-hæmoglobin is then reduced or converted into *reduced*-hæmoglobin.

which the hæmoglobin becomes practically saturated is low, being considerably less than half that of the oxygen in the alveolar air. The oxygen pressure in the lymph bathing the tissues is very low, because the cells of these tissues are continually using up oxygen; and, at this low pressure, the hæmoglobin rapidly loses oxygen and becomes partially reduced.

There is an evident advantage in the oxygen being thus held in loose chemical combination, for when a gas is held in physical solution in a fluid, the amount (weight) dissolved is directly proportional to the pressure, and in order to hold the same amount of oxygen in solution in the plasma as can be held in chemical combination in the hæmoglobin, the pressure would require to be enormous, so that it would be impossible, under existing atmospheric conditions, to keep the cells supplied with that amount of oxygen which they require.

Both in the lungs and in the tissues the plasma in which the red blood corpuscles float plays the part of an intermediary between the oxygen and hæmoglobin. The venous blood arriving at the lungs is poor in oxygen, and this poverty is shared by the plasma and the corpuscles; part of the hæmoglobin is in a reduced condition, the amount depending upon the pressure of oxygen in the plasma.[1] In the passage through the pulmonary capillaries, on account of the low pressure of oxygen in the plasma, a small amount of oxygen is first dissolved from the alveolar air, and if there were no hæmoglobin, this small amount would rapidly raise the pressure of oxygen in the plasma to that of the oxygen of alveolar air, and absorption

[1] The pressure of a gas in a fluid is often spoken of as its tension; thus, for example, one speaks of the oxygen tension of arterial or venous blood; but the term is of no great use, for this tension is measured by the pressure of the gas over the fluid when fluid and gas are in equilibrium, and gas is neither absorbed nor liberated, and hence it is quite correct to speak of the oxygen *pressure* in this sense. When the pressure on the surface of the fluid of the dissolved gas is diminished, as, for example, when a bottle of soda water is opened, then the pressure of the gas within the fluid is greater than its pressure outside the fluid, and gas is evolved from the fluid; and on the other hand, if the pressure of the gas on the surface be increased, more gas is dissolved. When a mixture of gases are exposed to the fluid, the amount of each taken up depends on its own pressure in the mixture, or, as it is called, its *partial pressure*, and not on the total pressure of the mixture.

would stop; but as the pressure of oxygen in the plasma increases, the hæmoglobin begins to combine with some of the oxygen, thus causing the pressure in the plasma to rise more slowly. So with a much smaller change in pressure, a much larger quantity of oxygen is taken up. Exactly the reverse change takes place in the tissues, for here oxygen is always being used up, and consequently the lymph bathing the cells is poor in oxygen, and the oxygen pressure in it is very low. There is accordingly a diffusion of oxygen from the plasma where the oxygen pressure is high into the lymph where the oxygen pressure is low, and the pressure in the plasma would soon fall, and so also the supply of oxygen to the cells, were it not that the lowered pressure cause the oxy-hæmoglobin to split up and yield a fresh supply of oxygen to the plasma. All the oxygen is never used up in any one circuit through an organ; there is always a large stock of reserve oxygen in venous blood, otherwise respiration could not be stopped for an instant without causing suffocation.

The passage of the carbon dioxide takes place in an inverse direction. The carbon dioxide is not certainly known to form any definite compound, such as oxygen does with the hæmoglobin. It is more soluble in plasma than oxygen is, and a certain amount is held in solution; another fraction is held in chemical combination, in part as sodium bicarbonate, in part with the proteids of the plasma, and also probably in part with the corpuscles. The pressure of the carbon dioxide in the plasma of the venous blood coming to the lungs is higher than its pressure in the alveolar air, and hence carbon dioxide is evolved, lowering the amount in the blood, and increasing the amount in the alveolar air. In the tissues, the lymph is highly charged with carbon dioxide, and hence there is a diffusion stream of carbon dioxide into the plasma, raising the pressure of carbon dioxide in it. In this way there is a continuous cycle of change, oxygen is taken in and carbon dioxide thrown out, in the lungs, and the supply of oxygen so obtained is borne by the circulating blood to the tissues, where it combines in part with hydrogen and in part with carbon. That part which combines with carbon gives rise to carbon dioxide, which

diffuses out from the cells to the lymph, from the lymph to the plasma, and in the plasma is carried to the lungs, where it is removed.

These changes may also be observed in blood outside the body, if the pressure of oxygen and carbon dioxide upon its surface be varied.

If blood which has been whipped, to prevent it becoming solid in clotting, be placed in a bulb which is connected with a mercurial air-pump, and the air within the bulb removed, then the gases contained in the blood are given off into the vacuum. At the same time, as the blood loses its oxygen it changes its colour from bright red to purple. If air be again admitted to the bulb, and especially if the blood be shaken up with it, the reverse change takes place, for the blood absorbs oxygen and turns back to red in colour.

The same change takes place when blood is left in contact with reducing agents, for these seize the oxygen from the oxy-hæmoglobin, and reduced hæmoglobin is formed. Thus if blood be shaken up with ammonium sulphide, and then allowed to stand for a few minutes, the ammonium sulphide is oxidized at the expense of the oxygen, and reduced hæmoglobin is formed. A certain amount of reducing power is possessed by the blood itself, and the amount of reducing substances in it increases on standing. Hence, when a large clot of blood, which has stood for some time, is cut into, although it is red on the surface where it has been in contact with the oxygen of the air, inside it is dark purple, almost black, in colour. Because the oxygen of the air has not been able to penetrate, and the reducing substances formed in the mass (or the oxidation processes going on there) have reduced the oxy-hæmoglobin.

The changes from the arterial to the venous condition, and back again from venous to arterial, may also be shown by bubbling alternately a stream of carbon dioxide, and one of oxygen, or atmospheric air, through some whipped blood. When the carbon dioxide is passed through, it carries away all the oxygen, and the blood becomes venous; when the air is passed through, it carries off the carbon dioxide, and leaves a

supply of oxygen to combine with the hæmoglobin, so that the blood becomes arterial.

Anything which prevents the combination of hæmoglobin with oxygen in the lungs, and so stops the supply of oxygen to the tissues, endangers the life of the animal. And if the supply be stopped completely for a short time (two to five minutes), or be insufficient for a longer period, the animal dies from suffocation, or *asphyxia.*

Asphyxia may be produced in several ways. It may be produced by stopping the windpipe, either from within by a bolus of food or a growth within the larynx or trachea, or from without, as in strangulation, thus preventing ingress of oxygen to the lungs. It may be occasioned by the lungs being filled with an inert gas or an inert mixture of gases containing too little oxygen, as in the after-damp of colliery explosions, or in the air of unventilated cellars or sewers; or by the lungs being filled with water, or some other fluid, as in drowning, so that the oxygen cannot enter. It may be also brought about by the air containing a much smaller quantity of a poisonous gas, such as carbon monoxide, which forms a more stable compound with hæmoglobin than does oxygen, and gradually combines with the hæmoglobin permanently, so that there is soon not enough left to act as an efficient oxygen carrier to the tissues.[1] Finally, it may be caused by paralysis of the nervous mechanism, and this may either be peripheral, as in the case of poisoning of the nerve endings of the respiratory muscles by curare, or central, as in poisoning by morphia, and in some cases of chloroform administration in excess.

When the supply of oxygen is insufficient, there is an excitation of the important nerve-centres lying in the medulla oblongata by means of the chemical stimulus of the too venous blood supplied to them.

Thus, the cardio-accelerator centre is stimulated and the heart beats faster. At a later stage the cardio-inhibitory centre is excited, and the heart beats slowly.

[1] Such suffocation occurs in poisoning from charcoal fumes, or from coal gas. In these cases the carbon monoxide compound has a cherry-red colour, which gives a characteristic hue to the lips and complexion.

The vaso-motor centre is irritated, and nerve impulses are despatched along the vaso-constrictor fibres, narrowing the small arterioles generally over the body, and thus raising the arterial pressure.

The respiratory centre itself is affected, and there is at first an increase in both the number and depth of the respirations, causing laboured breathing or dyspnœa.

But if the dearth of oxygen continue, the venous blood coming to these centres, which at first stimulated them, later has a sedative effect upon them; they become less active, and finally they are paralyzed and cease to act.

In consequence, the efforts at respiration become slow and gasping, there are, later on, exaggerated efforts at expiration only, and finally all respiratory attempts cease. During this period the vaso-motor centre also passes into slumber, the arterioles relax, and the arterial pressure falls. The heart-beats, which had become slow and irregular, in part from central stimulation, and in part from oxygen starvation of the cardiac muscle fibres, at length stop altogether from the latter cause. The arterial blood pressure falls to zero, the circulation ceases, and the animal dies.

Temporary dearth of oxygen, of much slighter extent, often occurs during the life of an animal. We see this evidenced in the laboured breathing which follows severe muscular exercise, and in the freer breathing which ensues after we have held our breath from any cause. On the other hand, a condition can easily be induced, known as *apnœa*, in which the animal has no desire for a brief time to breathe, on account of too great respiratory effort immediately preceding it.[1] Similarly, during muscular rest, and more especially during sleep, the respiration is quieter, because so much tissue oxidation is not going on, and hence less oxygen is required.

[1] An apnœic condition can readily be produced by taking *rapidly* about a dozen deep full breaths, when a short pause occurs, during which there is no desire to breathe. The condition is chiefly nervous in character, for it can be produced by distending an animal's lungs a few times with an inert gas, such as hydrogen. It is said, however, that apnœa produced by over-ventilation with oxygen lasts longer than that similarly produced by an inert gas.

The increase in respiration and heart action following violent muscular action is one of the best-known phenomena of our lives. The demand of the body for oxygen is suddenly very much increased, as well as the necessity for increased excretion of carbon dioxide, and there are obviously two means of meeting the occasion. First, a more rapid circulation, caused by increased action of the heart, carrying round to the tissues a larger volume of oxygen, and removing more carbon dioxide. At the same time, the circulation through the lungs is also made more rapid, so causing an increase in the intake of oxygen and in the output of carbon dioxide. Secondly, there is need for increased ventilation of the lungs, to throw out the excess of carbon dioxide discharged there, and to replace it by increased supplies of oxygen from the atmosphere; this is provided for by increased respiration.

These desired changes in the rate of action of heart and lungs are brought about by stimulation of the medullary centres, by the character of the blood sent to them by the heart; for this soon becomes more venous as the muscles go on working. There is, however, a maximum, and if the muscular activity be severe and prolonged, the changes in the blood begin to substitute another and reverse effect instead of exaggerated nervous activity; the person becomes *quite out of breath*, or *completely pumped out*, and has to slacken off or desist altogether.

The *rate of respiration* is slower in large than in small animals. One reason for this is that the surface of the skin is larger in proportion to their bulk in small than it is in large animals, and hence there is a greater comparative loss of heat which must be made good by a comparatively greater amount of combustion, and hence of respiratory exchange. For the same reason the rate of the heart-beat is quicker in small than in large animals, and there is usually a fairly constant correspondence between the cardiac and respiratory rhythms, one respiration, as a rule, taking place for about four heart-beats. For the same reason, heavy persons breathe more slowly than light persons, and the adult more slowly than the child. At birth, the rate of respiration is usually over 40 per minute; at five years of age it lies between 20 and 30; in middle age

at 16 to 17;[1] and in old age it somewhat increases again, averaging 17 to 19 per minute. In the same individual considerable variations in the rhythm are found, according to the circumstances under which observations are made. The effect of muscular exercise has already been alluded to; posture has also a great effect, the rate being fastest while standing, intermediate while sitting, and slowest while lying. The rate is also affected by the emotions and by sensory stimulation, such as application of cold water to the skin, or sudden pain. It can only temporarily be affected by direct application of the power of the will to that object. We can hold our breath voluntarily for a short time, but soon the desire to breathe becomes imperative, and in spite of the utmost voluntary effort to the contrary, respiration recommences. Also, we can breathe faster and deeper, or, on the other hand, more slowly than normal to us, for a short interval of two or three minutes; but it is impossible to keep up the attempt for any length of time, and, in spite of voluntary effort, we soon lapse back to the normal rate and strength of breathing.

[1] There are very wide variations from this average, any number between 10 and 24 per minute being found in different cases.

CHAPTER IX.

ANIMAL HEAT.

ALL animals may be divided into two great classes, according to the manner in which they react to changes in temperature of their surroundings. In one class, the temperature of the animal's body does not vary in summer or winter, but remains at a constant level, provided the animal is in a healthy condition; in the other class, the temperature of the body does vary with that of the surroundings,[1] rising when the air or water surrounding the animal grows warmer, and falling when the temperature of these environments sinks. As the temperature of the first class of animals is as a rule both higher than their surroundings and than that of the second class of animals, they are termed warm-blooded animals; on the other hand, the animals with variable body temperature are termed cold-blooded animals.[2] To the former class belong the mammalia (including man), the birds, and, to a certain extent, reptiles; to the latter, amphibia, fishes, and the invertebrates.

The temperature is not the same in all species of warm-blooded animals, but in the same species it is very constant, so much so that the "clinical thermometer" becomes an invaluable test for a feverish condition of the body, because the temperature then rises above normal.[3]

[1] Although it is not identical with that temperature, but somewhat higher.

[2] These terms, although they do not express the real difference between the two classes, are better than the uncouth terms, homoiothermal and poikilothermal, which have been proposed instead of them.

[3] The normal temperature in man, taken in the axilla or arm-pit, is 37° C. (equal to 98·6° Fah.); in the mouth it is slightly higher, 37·2° C., and in the rectum 37·6° C. The blood in the internal parts is somewhat warmer than this, and is hottest in the hepatic vein, where its temperature is about 39·5° C.

In a healthy condition of a warm-blooded animal the means provided in the body for regulating the temperature are so perfect that it does not rise or fall appreciably, no matter how great be the variation in the temperature of the surroundings, unless the exposure be very great and prolonged. When the temperature does vary considerably in either direction the condition of the animal becomes critical and life soon impossible.

A man may be placed in the rigour of a polar winter, or beneath the burning sun of the tropics in summer, but, provided he remain in a healthy condition, the temperature of his body will remain the same. As soon as the adjusting mechanism goes out of order this constant temperature is, however, no longer retained, and the temperature of the body may go above normal and remain above normal, although the patient be surrounded with ice-bags.[1] A person in a healthy condition can go into a very hot atmosphere, such as that of a Turkish bath, and remain there for some time, although the temperature may be sufficient to cook a beef-steak, but such a person must be supplied with some means of keeping cool; a large amount of water must be drunk to supply a large amount which is evaporated from the skin by the action of the heat-regulating mechanism of the body, and it is this constant evaporation of water which keeps down the temperature to a normal level. Again, a person who is exposed to a low temperature must be provided with means of producing heat to replace that lost from the body to surrounding objects, otherwise the temperature of the body would fall. A liberal supply of heat-producing food must therefore be eaten, which on combustion in the tissues yields heat.

Our clothing (and similarly the wool, feathers, and hair of animals) is another attempt, apart from ornament, to aid the heat-regulating mechanism of the body. Clothes and other coverings do not yield heat to the body, they merely, when, as is usually the case, the temperature of surrounding bodies is lower than that of the body, prevent loss of heat. They are

[1] In such a condition of fever the combustion in the tissues becomes excessive, and the regulating mechanism of the skin is unable to keep pace with it.

bad conductors which keep in the heat of the body, and so diminish the loss by conduction and radiation. White clothing reflects a good deal of heat, especially direct solar heat, and hence is cool because it prevents external heat from entering; on the other hand, black clothing absorbs solar heat readily, and hence is bad clothing for hot weather. In winter we require thick clothing of material which does not conduct heat well, such as wool, and in summer light clothing, both in texture and colour, which allows the heat produced in the body readily to escape, and also reflects as much as possible the external heat, and does not allow it to reach the body.

It is by being able in this way to modify his clothing at will, so materially aiding the natural heat-regulating agencies of his body, that man is enabled to inhabit all climates of the globe, from the tropics to the polar regions.

We have now to consider the ways in which heat is produced in and lost from the body, and in what manner the production and loss are so balanced as to produce an unvarying temperature.

Heat is produced in the body by chemical change (by oxidation of the food), and the heat so produced is distributed to the different parts, so as to maintain these nearly at the same temperature, by the blood-stream, which in this respect acts somewhat like a hot-water heating apparatus. The blood is heated by the chemical changes going on in the glands (especially in the liver) and in the muscles, so that the venous blood passing away from a muscle or gland is warmer than the arterial blood flowing to these parts. On the other hand, the blood in the capillaries of the skin is cooled, to some extent by radiation, but chiefly by evaporation, on the surface of the skin, of the water separated by the sweat glands. The blood is cooled by contact with the cooler skin, and therefore the venous blood passing away from the skin is cooler than the arterial blood passing to the skin.

Another way in which the body loses heat is by evaporation in the air-passages leading to the lungs. The air is taken into these passages in a more or less dry condition, and usually at a lower temperature than that of the body. Some heat is here

lost in raising the air to the temperature of the body, but this is inconsiderable when compared with the larger amount which is usually lost in saturating the air with aqueous vapour.

It takes a certain definite amount of heat to convert a definite weight of water into steam. The amount of heat which so becomes *latent* in the conversion is very large, for it takes nearly six times as much heat to convert boiling water into steam as it would have required to boil the same quantity supposing it ice-cold to commence with.

An amount of heat practically equal to this becomes latent whenever water becomes changed into vapour, *no matter whether the change takes place at the temperature of boiling water or not.* Hence the amount of heat lost in saturating the air, which is respired, with water vapour, and in evaporating from the skin, at the temperature of the air, the water furnished by the sweat glands, is very large.

The production of heat in the body is regulated by the heat value of the food consumed, and by the amount of exercise taken by the individual, so as to ensure the conversion of the whole of the chemical energy of the food into heat energy. The rates at which exercise is taken at different times also regulate the rates of combustion at these times. When an animal is exposed to cold surroundings, it runs or walks about, and uses its muscles so as to keep warm by the heat set free. Also, in order that the muscles may be supplied with chemical energy to convert into heat energy, it is necessary, if the exercise be long maintained, that the food-supply should be proportionately greater. The food is the ultimate source of the heat; the muscular energy the means whereby the animal is enabled to change chemical energy into heat energy; and the blood-stream the means of distribution of heat energy so provided. On the other hand, when an animal is placed in warm surroundings it becomes torpid, there is no need for great heat production, and consequently there is indisposition to muscular exercise, so as to produce as little extra heat as possible, while at the same time the loss of heat is increased by increasing the blood-supply to the skin. The appetite also becomes less keen, and a smaller amount of food suffices for the wants of the animal.

The amount of heat lost is regulated chiefly by the blood-supply to the vessels of the skin. When we are exposed to cold surroundings [1] the skin becomes pale and bloodless; when we are exposed to a warm atmosphere the skin becomes flushed from a rich supply of blood, and at a certain limit it becomes wet with perspiration. Before this limit is reached, however, there is a considerable amount of water being evaporated from the skin, only the evaporation rate exceeds the rate at which the sweat glands pour the sweat out, so that there is no accumalation of sweat on the surface. Even when the air in contact with the skin is hotter than the blood, there is no inconvenience felt so long as the air is not saturated with water vapour, and the person is liberally supplied with water. But if the hot air is also saturated with vapour it soon becomes oppressive, for then the sweat is not evaporated from the skin.

To sum up, then, the food is oxidized in the tissues by the agency of the oxygen carried by the hæmoglobin of the blood, and (with the exception of a small fraction which is turned into external work) all the chemical energy so set free is changed into heat. This supply of heat keeps the animal's body at a certain uniform temperature, which is usually above (but exceptionally may be below) that of its surroundings. To maintain this constant temperature, heat must be lost at variable rates, according to the changing temperatures of the surroundings, and this variation is accomplished mainly by varying the blood-supply to the more superficial and cooler part of the body, *i.e.* the skin, and by varying the amount of sweat secretion by nervous influence.[2] Besides losing heat

[1] Such an exposure produces a feeling which we refer to as cold, and say that we are cold, but in reality the body does not become any colder unless the exposure is very great, and then numbness and unconsciousness supervene. The feeling of cold is a warning to preserve the temperature of the body, and is not caused by any appreciable fall in temperature of the body generally, but merely of the skin. The same is true of the feelings produced by warmth.

[2] It is supposed that there are *specific* nerve centres for heat regulation, but the existence of these can scarcely be said to be experimentally proven. It is certain, however, that vaso-motor action on the skin, and sweat secretion, are invoked by nervous impulses, which may originate in part from the change in temperature of the skin, affecting peripheral sensory nerve-endings, and in part from minute changes in the temperature of the blood flowing through the nerve-centres.

through the skin, the body loses a considerable amount by the lungs, which is chiefly consumed in saturating the respired air with water vapour.

There are, besides, other minor sources of loss of heat to the body, which are, however, of no great importance compared to those considered above ; such, for example, as the food being occasionally taken into the body at a lower temperature than that of the body, while the excreta are voided at body temperature.

CHAPTER X.

EXCRETION.

THE waste products of the body are removed by four channels: viz. by the lungs, in the expired air; by the kidneys, in the urine; by the skin, in the sweat; and by the alimentary canal, in the fæces.

There is daily taken in along with the food a certain amount of water, and an equivalent amount of water to this, together with a much smaller amount arising from the oxidation of the hydrogen of the food, must daily be removed with the proper waste products of the body. This supply of water is as indispensable to the animal as is its food; it may be taken mixed with the food as water of the food, or it may be drunk alone, but in some form it must be taken into the body. We have seen that the food is absorbed from the alimentary canal in solution, and water is essential for this purpose. Certain of the waste products are removed from the body in solution, and here again water is necessary as a vehicle of removal. Further, a considerable amount of water is daily evaporated from the skin and lungs, and it is chiefly by *variations* in the amount of water so removed that the temperature of the body is regulated and kept at a constant level in spite of all changes in the temperature of its surroundings. There is thus a constant stream of water passed through the body which carries nutrient material to the blood, carries waste and impurity away from it, and aids in regulating the body temperature. Although this water cannot, strictly speaking, be regarded as a waste product, yet it is intimately connected with the removal of the waste products, and is, moreover, itself removed by the same channels, so that it can be conveniently considered along with them.

A very little of the waste material of the body, and a very

small proportion of the water are removed at the lower end of the alimentary canal in the fæces. Most of the solids of the fæces consist of waste shreds and débris of the food which have never formed, part of the body and are merely an indigestible residue of the food. The only portion which can be regarded as a true excretion of the body consists of a small amount of bile pigments, cholesterin and lecithin derived from the bile, and a small quantity of mucus secreted by the intestine epithelial cells and serving to coat the mass of fæces with a slimy surface to render its passage easy. The water of the fæces when these are in a normal condition forms but a small fraction of the quantity of water daily excreted; for the water taken in with the food, together with that added by the secretions which are poured in at the upper part of the alimentary canal, is rapidly removed by absorption in the lower part of the small intestine and in the large intestine, leaving the fæces at length semi-solid in consistency.

Practically, all the carbon dioxide excreted from the body, as well as a fair proportion of the water, is removed by the lungs in the expired air. The manner in which this is done has already been considered in connection with respiration; it remains to describe here the other channels of removal—viz. the skin and kidneys—and the constituents which they remove.

The skin chiefly removes water, accompanied by a small amount of inorganic salts and carbon dioxide, and traces of urea and other nitrogenous bodies.

The kidneys also remove water, but their chief function is the removal of practically the whole of the nitrogen formed in the degradation of proteid in the body. In addition, the kidneys remove the chief part of the inorganic salts excreted from the body, and certain salts of acids of the aromatic series, which are *chemically very stable*, and being formed in small quantities (either by changes going on in the body, or by bacterial action in the large intestine and absorption afterwards), cannot be broken up or oxidized in the body subsequently, and hence are excreted unchanged in the urine.[1]

[1] A considerable fraction of these aromatic compounds is excreted as sulphates, and in this way a portion of the sulphur formed in proteid

The relative amounts of water excreted respectively by lungs, skin, and kidneys are so variable with varying circumstances that no average figures of any worth can be given. In cold weather the relative amount excreted by the kidneys is increased, for then the blood-supply to the skin is diminished and the production of sweat is decreased because loss of heat by evaporation is not so much required. In a moist condition of the atmosphere the amount excreted by the lungs is diminished, and more especially if the air be both warm and moist; for the amount excreted by the lungs depends on saturation of the respired air with water vapour.

THE SKIN.

The skin forms a protective covering for the surface of the body. It is composed of two parts, termed the *cutis vera*, corium or dermis, and the *epidermis* or scarf skin respectively. Of these two the cutis vera is seated more deeply, and contains blood-vessels; while the epidermis is situated superficially, forming the surface, and has no blood-vessels. The epidermis is a thick stratified epithelium composed of a large number of layers of cells, which get different names at different depths, as their shape and consistency alters (see Fig. 92).

The superficial layers are flattened and horny, those nearest the surface being quite squamous, while the deeper layers are somewhat swollen. In these cells the nuclei have degenerated or at least become invisible. The thin pavement cells of the outer layers are gradually worn off by friction and abrasion, and are replaced by the swollen cells, which gradually become flattened as they near the surface, while in turn these cells are replaced by others from deeper layers. The deepest stratum of the horny layer, lying beneath the swollen layer above mentioned, is composed of clear compressed cells and is known as the *stratum lucidum*. These three strata of the horny layer merge by easy transition into each other. Beneath the horny portion lies the softer portion of the epidermis, which is known as

disintegration is got rid of. The balance is excreted as inorganic sulphates. The phosphorus formed in the breaking down of proteid appears in the urine as phosphates of the alkalies and alkaline earths.

the *rete mucosum* (of Malpighi); in this part the nuclei of the cells are still visible, and become more obvious as the cells are situated more deeply. The most superficial stratum is formed of a few layers of granular cells, and is called *stratum granulosum;*

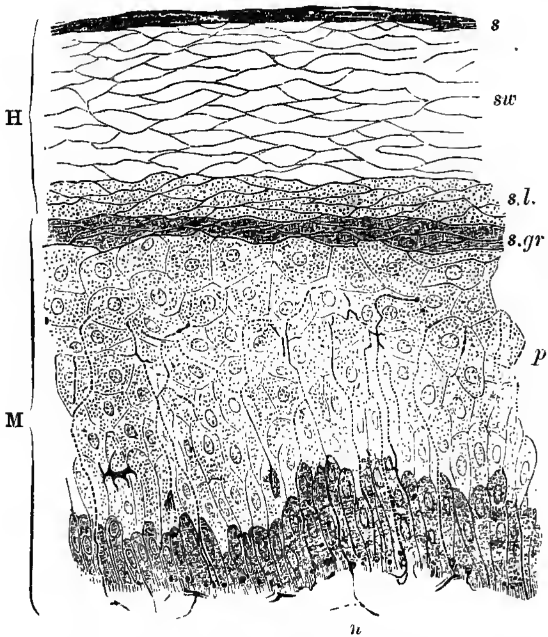

FIG. 92.—Section of epidermis. (Ranvier.)

H, horny layer, consisting of *s*, superficial horny scales; *sw*, swollen-out horny cells; *s.l.*, stratum lucidum; M, rete mucosum or Malpighian layer, consisting of *p*, prickle-cells, several rows deep; *c*. elongated cells forming a single stratum near the corium; and *s.gr.*, stratum granulosum of Langerhans, just below the stratum lucidum; *n*, part of a plexus of nerve fibres in the superficial layer of the cutis vera. From this plexus fine varicose nerve fibres may be traced passing up between the epithelium cells of the Malpighian layer.

beneath this lies a thick stratum of polygonal-shaped cells known as prickle cells (of Schulze), which have small intercellular channels between them for the passage of lymph for the nutriment of the cells. The channels are bridged over at intervals by processes from the cells, and when the cells are isolated for examination under the microscope these processes

give them a prickly appearance, from whence their name is derived. In the deeper layers the prickle cells tend to become columnar in shape, with the longer dimension perpendicular to the surface, and finally there is a layer of long columnar cells which rests upon the *cutis vera* lying immediately beneath it.[1] The under surface of the epidermis does not form a plane surface, but is thrown into ridges and hollows by *papillæ* which project into it (see Fig. 93); these papillæ bear

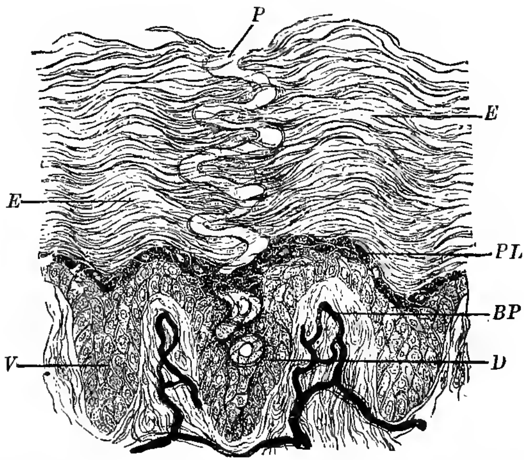

FIG. 93.—Duct of a sweat-gland passing through the epidermis. (Magnified 200 diameters.) (Heitzmann.)

BP, papillæ with blood-vessels injected; *V*, rete mucosum between the papillæ; *E*, stratum corneum; *PL*, stratum granulosum; *D*, sweat-duct, opening on the surface at *P*.

the blood-vessels which form capillary networks in the superficial part of the *cutis vera* projecting into the papillæ.[2] The outer free surface of the epidermis is also thrown into ridges corresponding to these, but not so deeply marked, which form the fine markings seen on the finger tips and elsewhere. Thus no blood-vessels enter the epidermis, but its deeper layers, where

[1] It is in this layer that the pigment is developed which gives colour to the skin in coloured people.

[2] The papillæ also lodge the terminations of the sensory nerve fibres for tactile sensation.

the cells are growing, are fed by lymph which exudes from the capillary networks of the cutis vera and can pass through the intercellular channels above mentioned.[1]

The cutis vera is composed of dense connective tissue, which gradually becomes more open in texture as it passes into the subcutaneous connective tissue which underlies it over most parts of the body. In this subcutaneous connective tissue fat may be largely developed, particularly over the abdomen, where it forms the *panniculus adiposus*, and over the buttocks. The cutis vera is richly supplied with blood-vessels, which are largely distributed to the surface, forming the capillary networks in the papillæ above mentioned.

The skin becomes modified at various parts, as at the lips, where it becomes thin and transparent, and passes gradually into the mucous membrane of the mouth; and on the inner surface of the eyelids and over the eyeball, where it is changed into a thin membrane, called the *conjunctiva*, which contains many sensory nerve-endings, and is hence extremely sensitive. Besides such modified parts the skin has modified structures all over it, which are known collectively as the *appendages of the skin;* these are the *nails*, the *hairs* and their glands (sebaceous glands), and the *sweat glands.*

The nails are formed by thickening and alterations of the *stratum lucidum* in certain well-known situations. The layers superficial to the stratum lucidum disappear in the course of development of the nail, and only a portion remains covered by these layers, forming the narrow band at the root. The nail lies on the nail-bed, or matrix, which is formed by a modified Malpighian layer with longitudinal ridges and grooves. The nail grows forward both from the end (nail groove) and from the posterior portion of the bed, and hence the free border is the thickest part of it. The substance of the nail is made up of clear compressed horny cells, each of which contains the remains of a nucleus.

The hairs are developed in the hair follicles (see Fig. 95), which are down-growths of the epidermis into the cutis

[1] On the other hand, fine nerve fibrils do pass between the cells of the deeper layers of the mucosum (see Fig. 92).

vera, or even into the subcutaneous tissue underlying this. The hair grows from the bottom of the follicle, where it is supplied with blood by a small vascular papilla which projects up into the somewhat expanded knob-like end of the hair. The hair substance is composed of a pigmented horny fibrous substance made up of long tapering cells, which can be separated by the use of acids. Externally the hair is covered

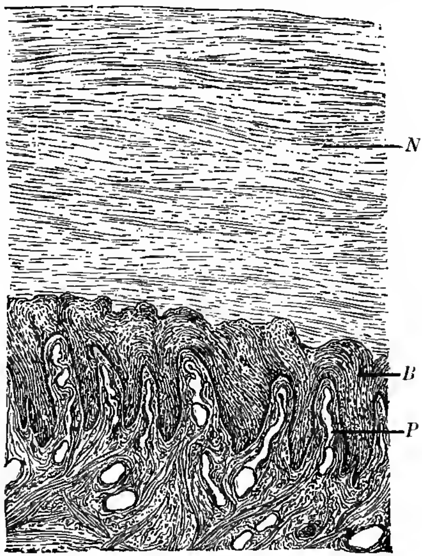

FIG. 94.—Section across the nail and nail-bed. (100 diameters.) (Heitzmann.) *P*, ridges with blood-vessels ; *B*, rete mucosum ; *N*, nail.

by a cuticle of imbricating scales, which fit against similar scales sloping in the opposite direction on the inner surface of the hair follicle.[1] The central part of the hair is occupied by a dark-looking material, and is known as the medulla. When minute air-bubbles are present in the medulla, or between the

[1] On account of these imbricating scales a coarse hair, when rubbed between finger and thumb, always moves towards the free end, just as does a blade of coarse grass when similarly treated. The object of the scales is to firmly fix the hair in its follicle.

fibrous cells of the hair, the hair acquires a white appearance when seen by reflected light. Each hair follicle has one or more small glands in connection with it which are known as the *sebaceous glands* (see Fig. 95). The ducts of these glands open into the hair follicle near its mouth. The glands secrete a fatty material called *sebum*, which is probably formed by the disintegration of the gland cells. The sebum imparts oiliness and softness to the hair. The hair follicle has also a tiny muscle (arrector pili) attached to it, composed of involuntary muscle fibres. This little muscle is attached as shown in the figure, and when it contracts it erects the hair or raises it at right angles to the surface of the skin.

Sweat glands are seen in a section of the skin from any part of the body, but more abundantly in the skin of the palm or sole, where they lie very

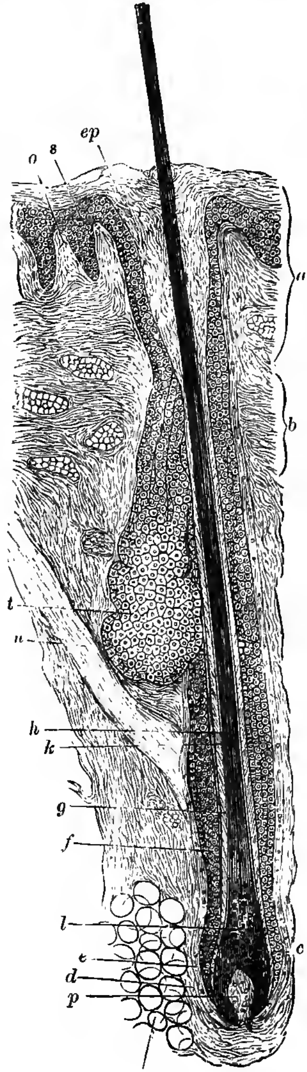

FIG. 95.—Hair follicle in longitudinal section. (Biesiadecki.)

a, mouth of follicle; *b*, neck; *c*, bulb; *d*, *e*, dermic coat; *f*, outer root-sheath; *g*, inner root-sheath; *h*, hair; *k*, its medulla; *l*, hair knob; *m*, adipose tissue; *n*, hair muscle; *o*, papilla of skin; *p*, papilla of hair; *s*, rete mucosum, continuous with outer root-sheath; *ep*, horny layer; *t*, sebaceous gland.

close together. They are coiled tubes lined with cubical or columnar epithelium, which lie deep in the cutis vera, and send their ducts, which are also coiled corkscrew fashion, up through the epidermis to open on the surface. The glandular part of the convoluted tube, in which the sweat is secreted, is lined outside by a basement membrane (see Fig. 96), inside which is a single layer of longitudinally placed fibres which

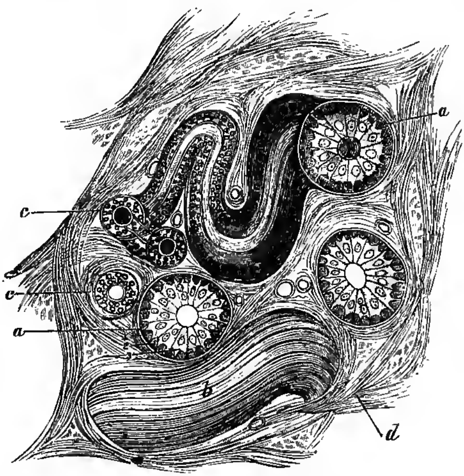

FIG. 96.—Section of a sweat gland in the skin of man. (E.A.S., Schäfer's "Essentials of Histology.")

a, a, secreting tube in section; *b,* a coil seen from above; *c, c,* efferent tube; *d,* inter-tubular connective tissue with blood-vessels. 1, basement membrane; 2, muscular fibres cut across; 3, secreting epithelium of tubule.

resemble involuntary muscle fibres, and more internally still surrounding the lumen [1] of the tubule there is a single layer of columnar cells which yield the secretion. The duct leading from the secreting portion is lined by two or three layers of cells, and the lumen is much narrower (see Fig. 96). The duct where it passes through the epidermis has no proper wall, and is merely an excavated channel between the epithelial cells.

[1] The lumen is the *central opening*, or *bore*, of a gland, alveolus, duct, or canal.

The Sweat.—Sweat is continually being produced by the sweat glands, even when it does not become obvious to the eye and wet the skin. It only accumulates on the skin when it is poured out by the glands faster than it can be evaporated off by the air in contact with the skin. When the sweat accumulates on the skin the condition is spoken of as *sensible perspiration;* while the term *insensible perspiration* is applied to the more normal case where it is produced at a less rapid rate than the air can take it up, so that it does not appear on the skin.[1] The more muscular work that is done the greater will be the amount of heat produced in a given time, and as this heat must be dissipated from the body, so that its temperature may remain constant, the greater will be the amount of sweat produced in a given time (see p. 192); and hence increased muscular work leads to sensible perspiration. Again, the hotter the air in contact with the skin, the more water must be evaporated from the skin surface to keep it cool, and so cool the blood circulating underneath, and thus keep the body temperature normal; so increased temperature of surroundings leads to increased sweat production, and tends to sensible perspiration. It is easily seen from these considerations that the rate of production of sweat is very variable, and hence that no accurate average estimate for the quantity per diem can be given, but it probably lies between one and three litres.[2] Each sweat gland is supplied by a small arteriole with a tuft of capillaries, and the blood-supply to these is controlled by vaso-motor nerve fibres; there are also secretory nerve fibres, through which the gland cells are directly stimulated to secrete. The sweat is a very watery secretion, and undoubtedly its chief function is to regulate the body temperature by water evaporation from the surface, and not to purify the blood by excretion of either organic or inorganic constituents. It contains only from 0·5 to 2 per thousand of total solids, of which about one-third is inorganic (chiefly sodium chloride), and the remainder

[1] The drier the air the more rapidly is the sweat evaporated, and hence, the temperatures being alike, "sensible perspiration" is more easily induced on a moist day than on a dry one.

[2] A litre is 1·76 pints.

organic. It has an acid reaction, probably due to volatile fatty acids; but after profuse sweating the reaction may become faintly alkaline. It also contains *traces* of urea and of carbon dioxide.

The Kidneys.

The urinary system consists of the kidneys, ureters, bladder, and urethra. The arrangement of these parts is shown in the

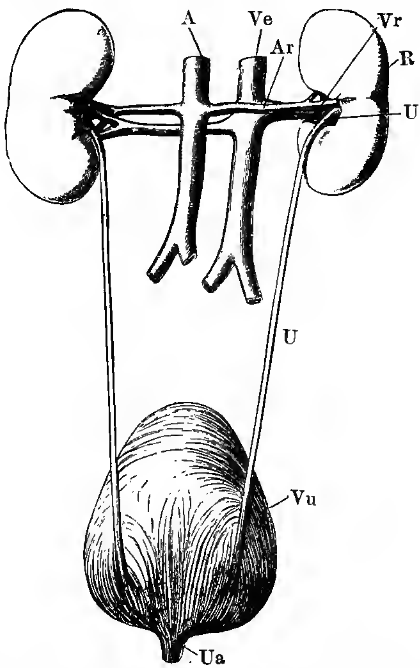

Fig. 97.—The kidneys, bladder, and their vessels. Viewed from behind. (Furneaux's "Physiology.")
R, right kidney; U, ureter; A, aorta; Ar, right renal artery; Ve, vena cava inferior; Vr, right renal vein; Vu, bladder; Ua, commencement of urethra.

accompanying figure as they appear from the back, and their situation in the abdomen has already been described. The urine is continuously secreted by the kidneys and trickles down the ureters into the bladder, where it accumulates, until

the distension of the bladder gives rise to a feeling of uneasiness, when it is voluntarily discharged through the urethra by the relaxation of a sphincter muscle placed at the commencement of that tube. Thus the kidneys secrete the urine, and the rest of the system is an accessory part for its temporary storage and convenient expulsion. Hence the kidneys are the most important portion, and we have to consider here their structure and the nature of their secretion or excretion.[1]

When a kidney is split open longitudinally and examined, it is seen to present an appearance resembling that shown in Fig. 98. The ureter enters at the concave part, called the hilum, and expands into a funnel-shaped dilatation, which is termed the *pelvis*. The pelvis divides into two or three primary divisions, and these again subdivide into a number of short wide tubes, which are named *calices*, or *infundibula*. These receive into their mouths the ends or papillæ of the pyramids of the kidney substance, and are attached all round the bases of these projections (see Fig. 98), so as to receive and carry away the urine which issues at the apices of the papillæ.

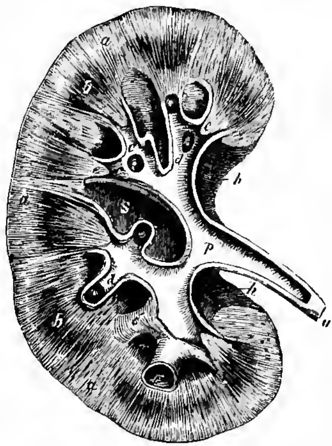

FIG. 98.—Plan of a longitudinal section through the pelvis and substance of the right kidney. One-half the natural size.

a, the cortical substance; *b*, *b*, broad part of two of the pyramids of Malpighi; *c*, *c*, the divisions of the pelvis named calices, or infundibula, laid open; *c'*, one of these unopened; *d*, *d*, summit of the pyramids or papillæ projecting into calices; *e*, *e*, section of the narrow part of two pyramids near the calices; *p*, pelvis or enlarged portion of the ureter within the kidney; *u*, the ureter; *s*, the sinus; *h*, the hilum.

On turning the attention to the kidney substance it can be

[1] The words "secrete" and "excrete" are often used indiscriminately. Any material separated by a glandular structure from the blood may be termed a secretion; but rigorously a secretion means a fluid material serviceable to the animal, and an excretion a waste product separated for removal from the body.

seen to be made up of two portions, differing in appearance and colour. The outer portion, lying immediately beneath the

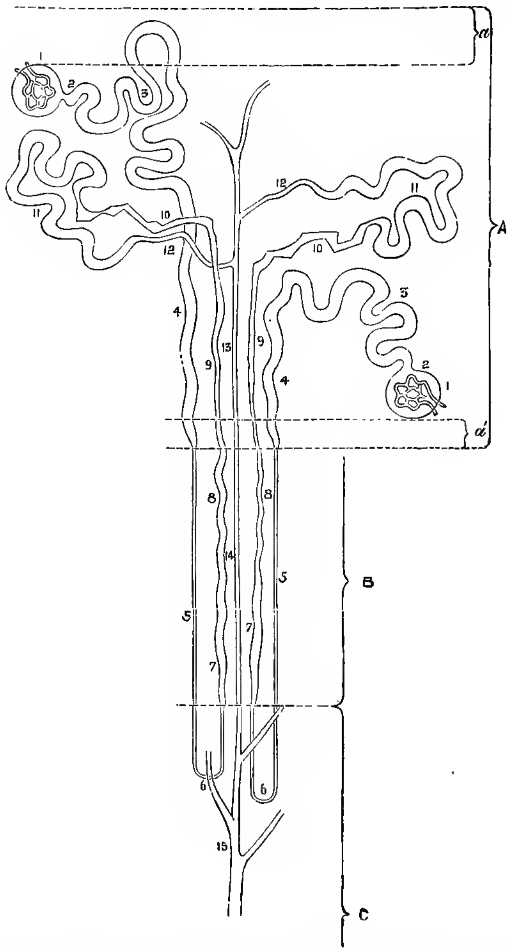

FIG. 99.—Diagram of the course of two uriniferous tubules. (Klein.)
A, cortex; B, boundary zone; C, papillary zone of the medulla; a, a', superficial and deep layers of cortex, free from glomeruli. For the explanation of the numerals, see the text.

fibrous capsule which surrounds the kidney, is termed the *cortex*. It is nearly uniform in its appearance, and is of a reddish brown colour. It extends inwards to the bases of the conical masses known as the *pyramids of Malpighi*, and also lies between contiguous pyramids. The pyramids constitute the *medulla* of the kidney; they vary in number in different animals; there are usually over twelve in the human kidney. The substance of the pyramids is distinctly striated, the striæ running from base to apex, and marking the course of the blood-vessels and uriniferous tubules (*vide infra*), which here run parallel to one another from the cortex towards the papilla or apex of the pyramid. The urine is secreted and carried to the papilla by minute tubules, which can be made out in the kidney substance with the aid of a dissecting lens. These tubules are termed *uriniferous* tubules, and by very patient dissection under a lens have been shown to have a very tortuous course in the kidney substance, which is represented *diagrammatically* in the accompanying figure.

Each tubule begins in the cortex in a dilated part which is known as a *Malpighian corpuscle*, or *glomerulus* (Fig. 99); this contains a much convoluted tuft of capillaries over which the tubule commences as the *capsule*. This capsule is composed of a double layer of thin pavement cells, one of which is reflected over the enclosed capillaries, while the other forms the outer wall of the glomerulus.[1] Thus the blood in the capillaries is separated from the uriniferous tubule only by the thin walls of the capillaries themselves and a single layer of flat cells forming the reflected layer of the capsule. The outer layer of the capsule narrows to a neck (2 in Fig.) at the opposite pole of the glomerulus to that at which the blood-vessel enters, and the cells change in shape from pavement to cubical. A tube is thus formed, which in the first part of its course is convoluted (*first convoluted tubule*, 3 in Fig.), next spiral (*spiral tubule*, 4 in Fig.), and then straight, running down the medulla in one of the pyramids. The tubule next turns back towards the cortex, forming the *loop of Henle* (5, 6, 7, 8, and 9 in Fig.), and in the cortex again becomes *zigzag*, and then convoluted (*second convoluted tubule*, 11 in Fig.), finally opening by a *junctional tubule* (12 in Fig.) into a *collecting tubule* (13 in Fig.). The collecting tubule, after receiving several junctional tubules, passes straight

[1] The arrangement is as if the capsule forming the end of the tubule had been a ball, against which the tuft of capillaries had been pushed so as to force in the ball and become enclosed in such a way that one layer formed a coat for the capillary tuft, while the other surrounded the whole.

down the medulla, and opens at the apex of a papilla as a *duct of Bellini* (15 in Fig.). The epithelium lining the tubule is set throughout on a basement membrane, and it differs in character in different portions of the tubule. In the first convoluted tubule and the spiral tubule, the cells are cubical and fibrillated, and the lumen is narrow. In the descending limb of Henle's loop and the loop itself, the cells are small and flattened, and leave a larger lumen; in the ascending limb they become cubical again; in the second convoluted tubule, they are cubical and fibrillated; in the junctional tubule, flattened; in the collecting tubule, clear and cubical; and in the duct of Bellini, clear and columnar.

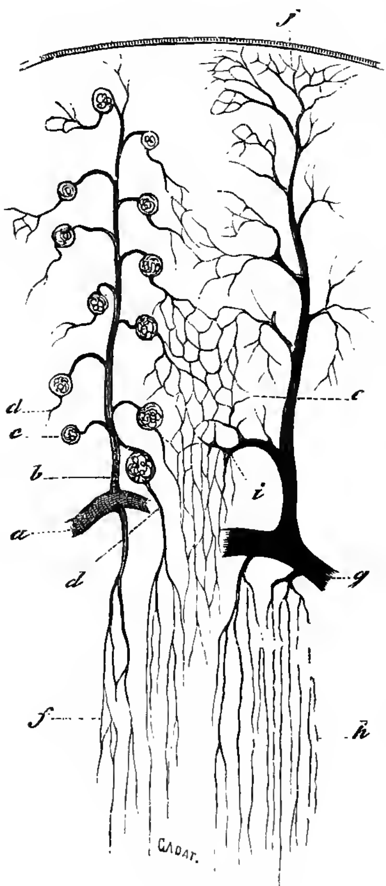

FIG. 100.—Vascular supply of kidney. (Cadiat.) Diagrammatic.

a, part of arterial arch; *b*, interlobular artery; *c*, glomerulus; *d*, efferent vessel passing to medulla as false arteria recta; *e*, capillaries of cortex; *f*, capillaries of medulla; *g*, venous arch; *h*, straight veins of medu'la; *j*, vena stellula; *i*, interlobular vein.

The arrangement of the capillary blood-vessels in the kidney is somewhat peculiar, for after being gathered up from the tuft of capillaries in the glomerulus by a small efferent vessel which leaves the glomerulus, the blood is again distributed to capillaries by the subdivision of this efferent vessel, and the second capillary system so formed surrounds the tubules and runs alongside them.

Each kidney is supplied with blood by a single large artery (renal artery) arising from the abdominal aorta, and the blood after circulating through the kidney returns to the inferior vena cava by a large vein (renal vein). These blood-vessels enter at the hilum, and passing into the kidney substance form a system of large branches lying between cortex and medulla. Smaller branches are given off from these (see Fig. 100), which pass to cortex and medulla; those which go to the cortex supply the glomeruli, and, as stated above, again form capillaries round the tubules; on the other hand, those which go directly to the medulla, form capillaries only once, viz. around the medullary portions of the tubules.

Urine Secretion.

The glomerulus looks, by reason of its flattened cells, like a simple filtering arrangement, for its cells do not appear of the proper type for selective secretion, such as are the cells lining other parts of the tubule. Still, the pores of the filtering apparatus must be very small, and unlike those of porous paper, for not a trace of the proteids of the blood-plasma comes through the glomeruli. It is probable that certain inorganic salts of the urine and a portion of the water pass through by filtration under pressure at the glomeruli, for the concentration of inorganic salts in urine approximates to that which they have in the blood, at any rate in the case of the *neutral* salts, such as sodium chloride. But, in the case of other constituents, it is obvious that the process of their separation is not one of simple filtration through the glomeruli. This is so in the case of the acid inorganic salts to which urine owes its acidity (*vide infra*), for the blood is alkaline, while the urine is normally acid. Still more so is this true for *urea*, that organic constituent which is present in urine in largest quantity, and is of most importance.

Urea is normally present in urine to the amount of 2 per cent., while in blood-plasma it is never in health present in more than $\frac{1}{100}$ of this concentration. Hence it cannot be present in the urine by filtration only, but must be actively secreted by some of the cells of the kidney. The kidneys also rapidly excrete any foreign material which may have got into the blood, such as drugs and medicaments, and these are found in the urine in much stronger solution than they could ever have been present in the blood, sure evidence that they are not removed by filtration.

Now the cubical cells lining certain parts of the uriniferous tubules possess all the characteristics of secreting cells, and it is obvious from analogy that these cells have some secreting function, as well from the appearance of the cells as from the convoluted course of the tubules, and the abundant blood-supply to their cells. Further, there is a certain amount of evidence that dissolved foreign substances are removed from the blood, not by the glomeruli but by the secreting cells of the tubules. Hence it is probable that a certain portion of the water and *some* of the inorganic salts are separated by filtration in the glomeruli; while other inorganic salts, notably those to which the reaction is due, the urea and other organic constituents, as well as any foreign substances dissolved by chance in the blood, are removed by the cells of the tubules. The secretion of the cells lining the tubule is thus washed down towards the collecting tubules by the watery secretion, or rather filtration, of the glomeruli.

The Urine.

The work of the kidneys is to regulate the condition of the blood, and to keep it pure by removing certain waste products formed in it as a result of the degradation of the food. The greater part of the carbon dioxide formed in the body, as already stated, is removed by the lungs, and a certain amount of water by the lungs and skin; all the balance of the work of maintaining the blood-stream pure is done by the kidneys.

The balance between kidney activity and condition of the blood is a very delicate one. If too much water has been absorbed, so that the blood has become slightly too dilute, the kidneys immediately commence to secrete a urine, which is much poorer in solid constituents than normal, and the amount of water in the blood is rapidly reduced. If the blood tends to become too alkaline, by formation from it of an acid secretion, as is the case in the first hours after a meal, then the kidneys at once commence to secrete a less acid, or it may be even an alkaline, urine and the alkalinity of the blood is kept unchanged in degree. Suppose some substance reaches the blood-stream which is an abnormal constituent there, then it

is at once treated by the kidney cells as an enemy and promptly expelled. Similarly, an excess of any normal constituent of the blood is treated as an abnormality and excreted. Blood normally contains about two parts per thousand of grape sugar, and so long as the concentration does not rise above this the kidney cells take no action with regard to it: but let the quantity increase, and at once the cells proceed to eliminate the excess in the urine. In diabetes, the sugar found in the urine is not formed in the kidneys, it is merely thrown out by them. Something has gone wrong elsewhere, and as a result there is an excess of sugar in the urine. Thus, the presence of sugar in the urine simply shows a normal attempt on the part of the kidney cells to remove this excess.

Similarly, the presence of the normal constituents of urine in that excretion is due to the preservation of a balance; these normal constituents are being continually produced in or poured into the blood-stream, and as continually are they removed by the kidneys, so that each is kept down to a certain normal percentage, which is in some cases very low. For example, if the amount of proteid in the food be increased, so also will be the amount of the products of proteid waste in the blood; and hence the amount of these waste products excreted in the urine will be correspondingly increased.

Chemical Composition of Urine.

Urine is a clear yellow or amber-coloured fluid which usually has an acid reaction. The acid reaction is not due to *free* acid, but to acid salts, and chiefly to the acid phosphate of sodium (NaH_2PO_4). The average daily amount of urine excreted by a man of average weight (66 kilograms, or 145 pounds) is 1500 cubic centimetres, but, as already mentioned, the daily amount varies very considerably with the amount of fluid drunk, and with the temperature of the surroundings. The total amount of solids in this quantity of urine averages slightly over 70 grammes, of which about 40 grammes is organic and 30 grammes inorganic matter.

The chief organic constituents of the urine are urea,

creatinine, uric acid, hippuric acid, pigment, and aromatic compounds in traces usually as sulphates.[1]

The inorganic salts are chiefly chlorides, sulphates and phosphates of *sodium*, potassium, calcium, magnesium, and ammonium.[1] *Urea* is the most important of the organic constituents, as it is in the form of urea that nearly all the nitrogen, of the proteid of the food, leaves the body. The chemical formula of urea is $CO<^{NH_2}_{NH_2}$; and it hence contains nearly half its weight of nitrogen.

Urea is not a very stable body, and is easily oxidized by suitable reagents to carbon dioxide, nitrogen, and water. Such a change can be induced by mixing with nitrous acid or sodium hypobromite, and may be represented by the following equation :—

$$CO(NH_2)_2 + 3NaBrO = CO_2 + N_2 + 2H_2O + 3NaBr$$

or, more simply, thus :—

$$CO(NH_2)_2 + 3O = CO_2 + N_2 + 2H_2O$$

This reaction is taken advantage of in order to estimate the amount of urea in any given sample of urine. A strongly alkaline solution of sodium hypobromite is used, which absorbs the carbon dioxide given off, and only allows the nitrogen to escape. From the volume of nitrogen given off, the amount of urea present can be determined.

After urea is voided in the urine it is attacked by bacteria, and ammonium carbonate is formed. The chemical action is one of hydrolysis ; thus—

$$CO(NH_2)_2 + 2H_2O = CO_3(NH_4)_2$$

Creatinine ($C_4H_7N_3O$) is a body of complex chemical constitution which is present in urine in small quantity. It is closely related to *creatine*, a disintegration product which occurs in muscle, especially on fatiguing the muscle.

Uric acid ($C_5H_4N_4O_3$) is a bi-basic acid which is not found in a free condition in the urine, but as acid sodium and potassium urates. It is not present in large amount in mammalian urine, but forms the greater part of the solid urine of birds and serpents. The free acid is much less soluble than its salts, and is hence thrown out of solution on standing, after adding a strong acid, such as hydrochloric acid, to urine. Still, the urates are not very soluble in water, and when they are present in excessive amount they

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[1] The daily amount of each of these constituents in grammes, in round numbers, is as follows: Urea, 33·2 : creatinine, 0·9: uric acid, 0·5 ; hippuric acid, 0·4 ; pigment and other organic substances; 10 ; chlorine, 7·5 ; sulphuric acid (SO_3), 2 ; phosphoric acid (P_2O_5), 3 ; sodium, 11 ; potassium, 2·5 ; calcium, magnesium, and ammonium, 1·2.

pass out of solution when the urine cools as a brick-red coloured deposit, which may be distinguished from other urinary deposits by the fact that it disappears on warming and reappears on cooling.[1] The amount of urates in the urine is increased by excess of proteid food, and by sudden excessive exercise.

Hippuric acid ($C_9H_9NO_3$) is a compound of amido-acetic acid with benzoic acid;[2] it is formed chiefly from the aromatic compounds present in vegetable food, and is hence present in much greater amount in the urine of herbivora. Its amount in the urine is increased by administration of benzoic acid.

The pigments of the urine, like those of the bile, are probably chiefly degradation products of hæmoglobin, but their chemical relationships to that substance have not yet been definitely made out.

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[1] Uric acid or urates may be further recognized by the red colour which they give when evaporated with strong nitric acid, turning purple on making alkaline with ammonia (murexide test). Uric acid is insoluble in water, but soluble in alkalies, urates being formed thereby.

[2] $$\underbrace{C_6H_5.COOH}_{\text{Benzoic acid.}} + \underbrace{CH_2(NH_2)COOH}_{\text{Amido-acetic acid.}} = \underbrace{COOH.CH_2(NH)COC_6H_5}_{\text{Hippuric acid.}} + H_2O$$

CHAPTER XI.

THE NERVOUS SYSTEM.

THE nervous system controls all the acts of the life of the higher animal. It determines all the movements of the body by initiating or preventing the contraction of the various muscles; it determines whether or not the cells of a gland shall be passive or active, and so whether the gland shall or shall not yield a secretion; it regulates by its action on the arterioles the supply of blood to the various parts, according to their needs; it gives the animal information as to its surroundings by conveying impulses from the outer world to certain structures, themselves belonging to the nervous system, which are capable of being acted upon so as to give rise to what are termed sensations; it further carries to these excitable structures forming part of itself impulses from the different parts of the body of the animal which give information as to the situation, condition, and well being of these parts; finally, it is an organ capable both of judging and estimating present sensations, and of retaining impressions of past sensations, as well as resolving its judgment on this complex into definite acts which constitute the life of the animal as a whole. The nervous system is hence the seat of intelligence, and the more complicated and highly developed the nervous organization is, the higher is the grade of intelligence of the animal. In the lowest forms of animal life no definite nervous system can be found. It first appears in the form of isolated knots of cells, called *ganglia*, to and from which long processes or fibres pass, which are outgrowths of the nerve cells. Higher in the scale of development these ganglia become arranged in series, or chains, along the axis of the body, and the ganglia are connected by fibres (nerve fibres)

passing between them. In vertebrate animals, the series or chain of ganglia becomes a connected whole, in which nerve cells are present along the entire length, and bundles of fibres, called nerves, are given off laterally in pairs on each side. The nerve cells and the fibres connecting them together become enclosed in a bony canal running along the vertebral column, from which the nerves issue between the successive vertebræ; further, at its upper end, the nervous system becomes very much enlarged, forming the brain, which is enclosed in the bony cavity of the skull called the cranium. The extent of development of the brain is an index of the intelligence of the animal and of its position amongst the vertebrates. It is most developed in mammals, most of all in man; and amongst various races of men, the most highly civilized and intellectual have also the most highly developed brains.

The nervous system is usually described as divided into two parts, of which one is much greater than the other. The part enclosed in the cranium and in the neural canal of the vertebral column, with the nerves attached to it, is spoken of as the *central* nervous system, or *cerebro-spinal* system, and a double chain of ganglia situated on either side of the vertebral column in the neck, thorax, and upper part of the abdomen, and connected to one another and to the central nervous system by nerve fibres, is known as the *sympathetic* system. This sympathetic system is really an outgrowth of the cerebro-spinal system. The part of the nervous system lodged in the hollow of the cranium, and in the neural canal, forms the cerebro-spinal axis, consisting of the brain and spinal cord.

By far the greater part of the volume of the brain in man and in the higher mammals is taken up by the *cerebral hemispheres* which occupy the upper and front part of the cranium (see Figs. 101 and 102). The two hemispheres are separated from each other by a deep cleft (the longitudinal fissure), but are united to each other at the bottom of this fissure by a thick band of nerve fibres (the *corpus callosum*), passing from the one hemisphere to the other in order to carry nerve impulses across from one to the other. The surface of each hemisphere is marked by deep groves termed *sulci*, between which are the

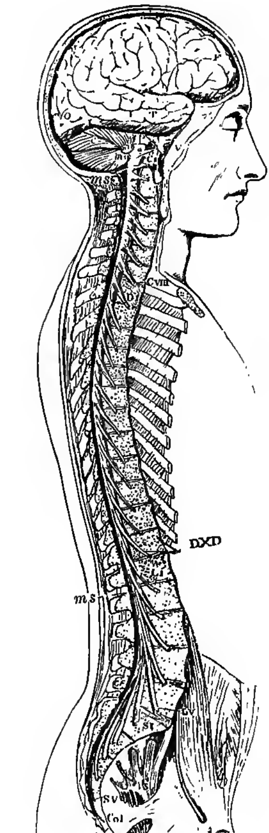

FIG. 101.—View of the cerebro-spinal axis. (After Bourgery.)

The right half of the cranium and trunk of the body has been removed by a vertical section, and the roots of all the spinal nerves of the right side have been dissected out and laid separately on the several vertebræ opposite to the place of their natural exit from the cranio-spinal cavity.

F, T, O, frontal, temporal, and occipital lobes of cerebrum; C, cerebellum; P, pons Varolii; *m o*, medulla oblongata; *m s*, *m s*, point to the upper and lower extremities of the spinal cord; *c e*, on the last lumbar vertebral spine, marks the cauda equina; C I, the sub-occipital or first cervical nerve; C VIII, the eighth or lowest cervical nerve; D I, the first dorsal nerve; D XII, the last dorsal; L I, the first lumbar nerve; L V, the last lumbar; S I, the first sacral nerve; S V, the fifth; Co I, the coccygeal nerve; *s*, the left sacral plexus.

eminences known as the *convolutions.* The purpose of this is to increase the surface and so make room for a greater number of nerve cells, which are all situated in a thin greyish coloured layer over the surface, forming what is called the *cerebral cortex.* It is in the cells of this cortical layer that all the nerve impulses which start from the cerebrum originate. The deeper part of the cerebral substance is white in colour and contains no nerve cells, but only nerve fibres passing away from or leading to the

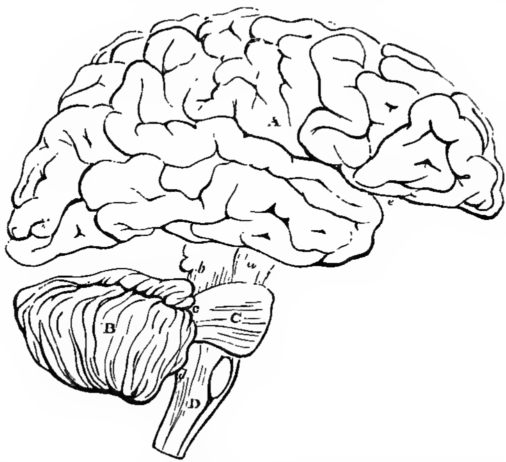

FIG. 102.—Plan in outline of the encephalon, as seen from the right side. ⅓

The parts are represented as separated from one another somewhat more than natural so as to show their connections. A, cerebrum; *e*, fissure of Sylvius; B, cerebellum; C, pons Varolii; D, medulla oblongata; *a*, peduncles of the cerebrum; *b*, *c*, *d*, superior, middle, and inferior peduncles of the cerebellum; the parts marked *a*, *b*, form the isthmus encephali.

cells of the cortex and serving to carry impulses to or from these cells. By these nerve fibres, the cells of the cerebral cortex are placed in communication with the other parts of the central nervous system where other cells are situated. Each cerebral hemisphere is hollow, and the small cavity inside is known as the *ventricle.* On the floor of this ventricle are situated certain other nerve centres containing nerve cells to which some of the fibres of the cerebral cortex run, and other fibres pass from these intermediate centres to different parts of the brain. By far the

greater number of the fibres belonging to the cerebral cortex, however, after being gathered up into a fan-shaped bundle (known as the *corona radiata*), from all over the surface of the hemisphere, unite to form a thick stalk or bundle of fibres, which passes from the hemisphere backwards and downwards towards the spinal cord and is known as the *crus cerebri* (see Fig. 102). The two *crura cerebri* form a narrow part of the brain

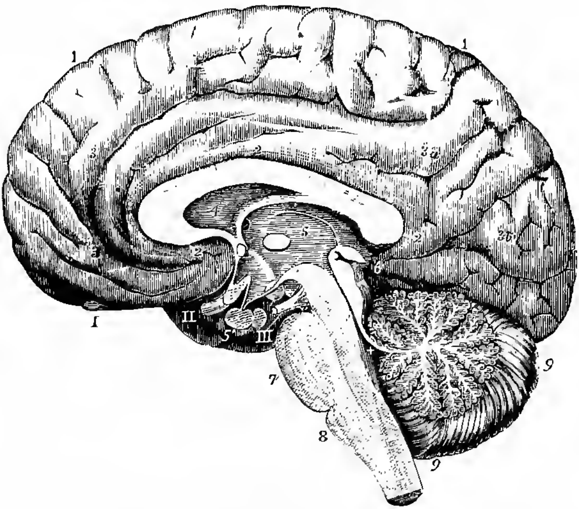

FIG. 103.—Right half of the brain divided by a vertical antero-posterior section (from various sources and from nature. (Allen Thomson.)

1, 2, 3, 3*a*, 3*b*, are placed on convolutions of the cerebrum; 4, the fifth ventricle, and above it the divided corpus callosum; 5, the third ventricle; 5′, pituitary body; 6, corpora quadrigemina and pineal gland; +, the fourth ventricle; 7, pons Varolii; 8, medulla oblongata; 9, cerebellum; I, the olfactory bulb; II, the right optic nerve: III, right third nerve.

which is known as the isthmus or mid brain. In the mid brain there are certain other intermediate cell stations, or nuclei, of grey matter, containing nerve cells, and to these certain of the fibres of the crura cerebri pass, but by far the greater number pass downward towards the spinal cord. Some of these fibres pass into[1] the cerebellum and form the superior cerebellar peduncle.

[1] The expression "pass into" is here used in an anatomical sense; in a physiological sense some of these fibres pass into the cerebellum and carry impulses to it, while others pass out and carry impulses from it.

The *cerebellum*, like the cerebrum, consists of two exactly similar hemispheres, which are also deeply indented on their surface, giving rise to convolutions, but not in an exactly similar manner to the cerebrum (see Fig. 103).

The two cerebellar hemispheres are further united to each other by a thick band of fibres called the middle cerebellar peduncle, which forms part of the brain known as the *pons Varolii*.[1] A third peduncle, called the inferior peduncle, connects each cerebellar hemisphere with the spinal cord below. The cerebellum is thus connected both with the parts of the brain above and below and with its fellow of the opposite side. It has, like the cerebrum, a cortex which contains nerve cells, and the white part underlying this cortex contains only nerve fibres.

A great number of the nerve fibres of the crura cerebri do not pass off laterally to the cerebellum, but pass down underneath the crossing fibres of the middle cerebellar peduncle to reach the cord (see Fig. 106); these are joined in this course by the fibres of the inferior cerebellar peduncle, and together these bundles of fibres make up the greater part of the *medulla oblongata*, which is the name given to that part of the brain intervening between the pons Varolii and the spinal cord. In the medulla there are imbedded certain masses of grey matter containing nerve cells, and here several pairs of nerves take origin; also at this part, the white and grey matter begin to change their relative situation and tend to assume that which they occupy throughout the spinal cord. In fact, the medulla may be regarded as the part where transition from brain to cord takes place. We have seen that in the hemispheres of the brain the nerve cells lying in the *grey* matter occupy the cortex or external part; while the nerve fibres conducting the impulses from these nerve cells lie more internally, forming the *white* matter. In the spinal cord the position is reversed, for the cells in the grey matter occupy the central part of the cord and are everywhere surrounded by nerve fibres forming the white

[1] A band of fibres so uniting two bilaterally similar parts of the central nervous system is known as a *commissure;* thus the *corpus callosum* is a great commissure, so is the middle cerebellar peduncle, and there are similar commissures uniting the grey masses in the spinal cord.

part of the cord. These nerve fibres run parallel to each other down the length of the cord, in long strands. As they pass down the cord their number, and hence the volume of the white matter, decreases; for they gradually pass in as they go to communicate with the nerve cells at different levels in the cord. The purpose of these fibres is to give communication between the cerebrum and other parts of the brain and the nerve centres of the spinal cord, as well as intercommunication between the different parts of the cord itself.

At the lower and anterior part of the medulla oblongata a large number of fibres, coming from the cerebral cortex, cross over to the opposite side and decussate in bundles as they cross from each side, thus forming what is called the *decussation of the pyramids* (see Fig. 106); for these fibres form part of what is known as the *pyramidal tract.* The pyramidal tract commences in the nerve cells of a portion of the cerebral cortex surrounding a transverse fissure in the brain called the fissure of Rolando (near A, Fig. 102). This region of the cerebral cortex is known as the *motor area*, because the nerve cells of this area regulate voluntary motion, and when certain portions of the area are injured, voluntary motion, in definitely corresponding parts of the body, is paralyzed.[1] From the motor area of the cortex the pyramidal fibres pass down in the corona radiata to the crus cerebri of the same side, and so reach the medulla, where at the decussation about four-fifths of them cross, but the proportion is very variable. In the cord there are thus two pyramidal tracts on each side—that which has come from the opposite side of the brain occupies the postero-lateral part of the white matter of the cord, and is known as the *crossed pyramidal tract;* while that which has not crossed at the decussation lies in the anterior part of the white matter, and is termed the *direct pyramidal tract.* These fibres pass eventually to motor nerve cells [2] lying at different levels in the cord, and hence the tracts decrease in

[1] Also, on stimulating different parts of this area electrically, movements of different parts take place; and so well localized are the areas for different movements, that it can be predicted with precision what movement will follow stimulation of a definite point of the motor cortex (see Fig. 112).

[2] These cells lie in the anterior horn of the grey matter of the cord (*vide infra*).

volume as the cord is descended. Although the fibres of the direct pyramidal tract do not cross at the decussation, they do all cross at various levels lower down in the cord, and are all eventually connected with nerve cells of the opposite side of

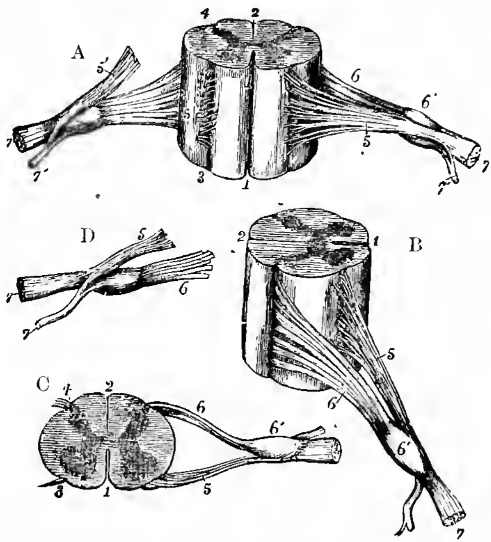

FIG. 104.—Different views of a portion of the spinal cord from the cervical region with the roots of the nerves. Slightly enlarged. (Allen Thomson.)

In A, the anterior or ventral surface of the specimen is shown, the anterior nerve root of the right side having been divided; in B, a view of the right side is given; in C, the upper surface is shown; in D, the nerve roots and ganglion are shown from below. 1, the anterior median fissure; 2, posterior median fissure; 3, antero-lateral impression, over which the bundles of the anterior nerve root are seen to spread (this impression is too distinct in the figure); 4, postero-lateral groove into which the bundles of the posterior root are seen to sink; 5, anterior root; 5′, in A, the anterior root divided and turned upwards; 6, the posterior root, the fibres of which pass into the ganglion, 6′; 7, the united or compound nerve; 7′, the posterior primary branch, seen in A and D to be derived in part from the anterior and in part from the posterior root.

the cord. It follows from this complete crossing of the motor fibres that an injury to the motor area of the brain will cause motor paralysis, not on the same side of the body as the injury, but on the opposite side.

When the spinal cord is cut across, or when thin sections of it are made and examined with the microscope, the situation of the grey and white matter, and the structure of each, can be

made out. The grey matter is arranged in two somewhat comma-shaped masses, connected by commissures passing in front of and behind a small central foramen, which is the *central canal* of the spinal cord (see Fig. 105).

The thicker end of each mass is called the anterior horn, or cornu, and contains many large conspicuous nerve cells,

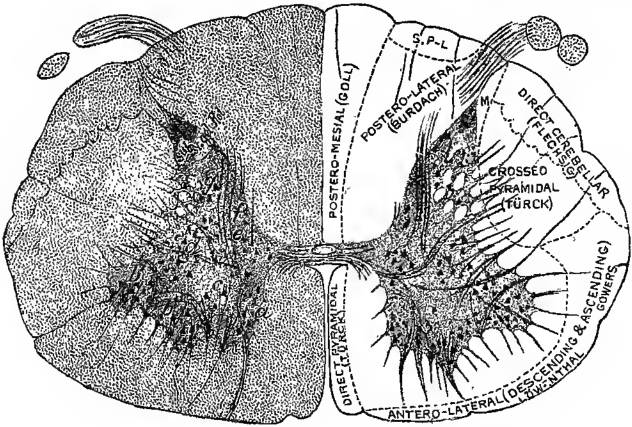

FIG. 105.—Section of spinal cord in the lower cervical region. (E. A. S., Quain's "Anatomy.") The names shown here designate the various tracts in the white matter.

which are connected with motor nerve fibres passing to the peripheral parts of the body. The more pointed posterior part is called the posterior horn or cornu, and to this the sensory fibres pass which convey sensory impulses from the periphery (skin, etc.) towards the central nervous system.

The spinal nerves arise in pairs from the cord at intervals, which correspond roughly to the vertebræ, and the nerves issue between the vertebræ. Each nerve arises by two roots (see Fig. 104) from the cord, which are termed the anterior and posterior roots. On the posterior root a ganglion is situated, containing the nerve cells belonging to the fibres of that root, and all these fibres are *sensory* or *afferent*,[1] that is, they carry nerve

[1] "Afferent" means leading impulses to the central nervous system, and "efferent" leading impulses from the central nervous system: these are more general terms than "sensory" and "motor;" for all fibres leading nerve impulses to the cord are not sensory, and all leading from are not motor.

impulses inwards from the periphery to the posterior horn of the grey matter. The anterior root has no ganglion, and the nerve cells belonging to the fibres contained in this root are situated in the anterior horn of the grey matter. All the fibres of the anterior root are *motor* or *efferent*,[1] and convey nerve impulses from the central nervous system (anterior cornu) to the periphery.

The union of the two roots gives rise to the mixed nerve trunk, in which some of the fibres are afferent and some efferent. These facts as to the nature of the fibres in the two spinal nerve roots have been made out from the effects of section or of stimulation of each. When *all* the posterior roots of the nerves going to a limb are cut, sensation is lost in the limb, but it can still be moved. When, on the other hand, all the anterior roots are cut, sensation is still present in the limb, but it cannot be moved. Again, when the central end of the divided anterior root is stimulated electrically no effect is obtained; but when the peripheral end is so stimulated there is a movement of the limb. Further, when a similar experiment is made with the posterior root no effect is obtained now on stimulating the peripheral end; but with the central end there is evidence that an impulse has reached the cord in the movements of the opposite limb, or of all the other limbs of the body, according to the strength of the stimulus, or of the same limb if the anterior roots passing to it have not been divided.

The spinal cord does not extend quite to the end of the neural canal, but passes at the lower end of the body of the first lumbar vertebra into a slender filament called the *filum terminale*. The lower lumbar nerve roots pass downward, to their exit, parallel to the filum terminale, forming together what is known as the *cauda equinæ*.

Besides the spinal nerves there are twelve other pairs of nerves which arise from the cerebro-spinal axis. These nerves leave the brain within the cranium, and are hence called the *cranial nerves*. Enumerated from before backward the cranial nerves are as follows:—

I. *The olfactory nerves* arise from the olfactory tract, which is an outgrowth from the frontal lobe of the cerebrum. About

[1] See note on p. 226.

a dozen filaments pass from the olfactory tract to the mucous membrane (olfactory mucous membrane) lining the upper part of the nasal passages.

II. The *optic nerves* passing backward, one from each eye, meet in the middle line to form the optic commissure, from which the two optic tracts pass outward and backward (see Fig. 106) to be distributed to those intermediate cell stations, already mentioned (see p. 221), in the floor of the ventricle of the cerebrum and in the mid brain. These intermediate stations are connected by other fibres with the posterior part of the cortex of the cerebrum (occipital lobe), which is chiefly concerned with visual sensations (see Fig. 112, p. 242).

III. The *oculo-motor* nerves supply some of the muscles of the eyeball and of the interior of the eye.

IV. The *trochlear* nerves supply one of the muscles of the eyeball (superior oblique).

V. The *trigeminal* nerves are so called because they divide into three chief branches (see V, 1, 2, and 3, Fig. 106) : viz. (*a*) the *ophthalmic* division, which chiefly supplies sensory fibres to the eyeball, to the interior of the eye, and to neighbouring parts; (*b*) the *superior maxillary* division, which supplies sensory fibres to the skin of the temple and cheek, to the teeth of the upper jaw and surrounding parts; and (*c*) the *inferior maxillary* division, which supplies sensory fibres to the mucous membrane on the inner surface of the cheek, to the anterior two-thirds of the tongue, and the floor of the mouth, to the teeth of the lower jaw, to the chin, lower lip and margin of the jaw, and to the muscles of mastication. This division also supplies motor fibres to the muscles of mastication.

VI. The *abducent* nerves are the smallest of the cranial nerves, and are merely motor nerves in each case to that muscle which causes outward movement of the eyeball (external rectus).

VII. The *facial* nerves supply motor fibres to the muscles of the face, and secretory fibres to the salivary glands.

VIII. The *auditory* nerves supply the organs of hearing; they also send fibres to peculiar structures in the internal ear, called the semi-circular canals, which are concerned with the sensation of equilibrium.

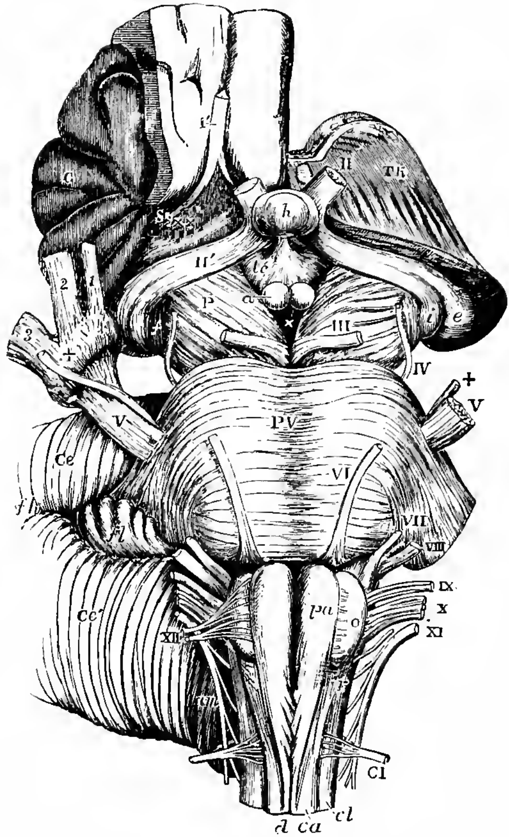

FIG. 106.—View from before of the medulla oblongata, pons Varolii, crura cerebri, and other central portions of the encephalon. (Allen Thomson.) Natural size.

1', the olfactory tract cut short and lying in its groove; II, the left optic nerve in front of the commissure; II', the right optic tract: *Th*, the cut surface of the left thalamus opticus; C, the central lobe or island of Reil; *Sy*, fissure of Sylvius; × ×, anterior perforated space; *e*, the external, and *i*, the internal corpus geniculatum; *h*, the hypophysis cerebri or pituitary body; *tc*, tuber cinereum with the infundibulum; *a*, one of the corpora albicantia; P, the cerebral peduncle or crus; III, close to the left oculo-motor nerve; ×, tbe posterior perforated space. PV, pons Varolii; *V*, the greater root of the fifth nerve; +, the lesser or motor root; *VI*, the sixth nerve; *VII*, the facial; *VIII*, the auditory nerve; *IX*, the glossopharyngeal; *X*, the pneumogastric nerve; *XI*, the spinal accessory nerve; *XII*, the hypo-glossal nerve; C I, the suboccipital or first cervical nerve; *p a*, pyramid; *o*, olive; *d*, anterior median fissure of the spinal cord, above which the decussation of the pyramids is represented; *c a*, anterior column of cord; *r*, lateral tract of bulb continuous with *c l*, the lateral column of the spinal cord.

IX. The *glossopharyngeal* nerves are the nerves of taste to the posterior third of the tongue; they are also sensory nerves for this region and the neighbouring parts, as well as the upper part of the pharynx.

X. The *pneumogastric*[1] nerves have a very important and wide distribution. From the wandering course of the nerve it is also called the *vagus*. It contains both afferent and efferent fibres, and sends branches to the pharynx, larynx, œsophagus, heart, lungs, stomach, intestine, pancreas, and liver. By means of these branches it exercises an important control on the operations of swallowing, digestion, and secretion, and also plays a part in regulating the rhythm of respiration and of the heart-beat.

It contains both afferent and efferent fibres; among the afferent fibres are those to the respiratory centre, which differ in their action according to the part of the distribution of the nerve from which they come. When both vagal trunks are cut in the neck, the respiration becomes very slow, and if now the central end of one vagus be stimulated the respiratory rhythm is greatly quickened, showing that the vagus trunk contains afferent fibres,[2] which normally have an accelerating effect on the rhythm of respiration. On the other hand, if those fibres of the vagus contained in its superior laryngeal branch, which supply the mucous membrane of the larynx, be stimulated, respiration is inhibited, inspiration is stopped, and a violent expiratory effort takes place. Such a stimulation naturally takes place when a particle of food or other foreign matter comes in contact with the mucous membrane of the larynx, and the purpose of the expiratory effort so produced is to expel the particle and prevent it from dropping into the trachea. Examples of the distribution of the efferent fibres of the vagus are: the motor fibres to the muscles of the larynx in the inferior laryngeal branch; the secretory fibres to the glands of the mucous membrane of stomach and intestine, and to the pancreas which stimulate the cells of these glands and cause them to secrete during digestion; the cardio-inhibitory fibres to the heart, which slow the rhythm of that organ or stop it temporarily if stimulated sufficiently strongly.[3]

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[1] So called because it gives off branches to both lungs and stomach.

[2] These afferent fibres produce their effect reflexly (see p. 237): when stimuli passing along them reach the respiratory centre situated in the medulla oblongata, reflex motor stimuli are sent out from this centre, which travel along the motor nerves to the respiratory muscles and cause these muscles to contract.

[3] Such stimuli constantly reach the heart along the vagi during life, as is shown by the great quickening in the heart-beat which always follows the cutting of both vagi. That the vagi here act as efferent nerves carrying impulses to the heart is shown by the fact that electrical stimulation of the peripheral end of the cut nerve (*i.e.* the end next the heart) causes slowing, or if strong enough *temporary* stoppage of the heart.

XI. The *spinal accessory* nerves arise by two different roots, one in the medulla and the other in the lower cervical part of the spinal cord. This nerve gives branches to the vagus, and it has been shown that it is to fibres derived from the medullary origin of the spinal accessory, and which join the vagus, that the cardio-inhibitory action of the vagus is due. The fibres which arise from the cervical spinal cord chiefly supply motor fibres to certain of the muscles of the neck.

XII. The *hypoglossal* nerves take origin from the medulla oblongata, and are motor nerves which supply the muscles of the tongue.

The *sympathetic* nervous system consisting, as has been already mentioned, of a double chain of ganglia (*i.e.* knots of nerve cells) connected to each other by nerve fibres, is an outgrowth of the central nervous system, and is connected to it at intervals along its length by strands of nerve fibres (*rami communicantes*). The fibres of the sympathetic system act chiefly on the vascular and visceral system, sending branches to the secreting glands, which control the character of their secretion; to the walls of the small arteries (*vaso-motor fibres*), controlling their calibre; to the heart, quickening its rhythm, and so antagonizing the vagus; to the intestinal muscular walls, controlling their peristalsis; to the iris of the eye, increasing the diameter of the pupil (see p. 269); and, generally, the sympathetic fibres may be said to carry out operations necessary to the well-being of the animal, but outside the control of its will. On the other hand, the nerve impulses of the central nervous system are partially voluntary and partially involuntary.

We may next briefly consider the minute structure of the nerve cells, nerve fibres, and nerve endings which form the essential parts of the nervous mechanism.

If one of the peripheral nerve trunks be exposed, such as the sciatic nerve in the thigh, and a small length be cut out and teased with needles in normal saline solution, it will be found that the nerve is not easily broken across, but that it divides rather easily into strands along its length. If now a minute strand be taken and teased out in saline solution and then examined under the microscope, it will be found

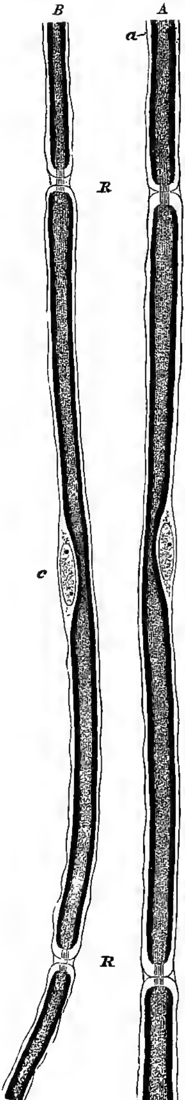

FIG. 107.—Portions of two nerve fibres stained with osmic acid (from a young rabbit). (425 diameters.)

R, *R*, nodes of Ranvier, with axis cylinder passing through. *a*, primitive sheath of the nerve; *c*, opposite the middle of the segment, indicates the nucleus and protoplasm lying between the primitive sheath and the medullary sheath. In A the nodes are wider, and the intersegmental substance more apparent than in B. (Drawn by J. E. Neale.)

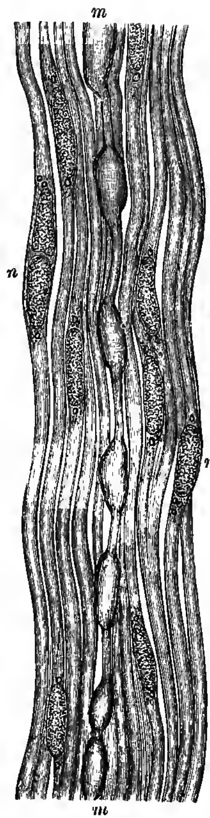

FIG. 108.—A small bundle of nerve fibres from the sympathetic nerve. (Key and Retzius.)

The bundle is composed of pale nerve fibres, with the exception of the fibre *m*, *m*, which is inclosed here and there by a thin medullary sheath; *n*, *n*, nuclei of pale fibres.

that the nerve is made up of bundles of long fibres which run parallel to one another in the length of the nerve without branching. The nerve fibres are bound compactly together by connective tissue which envelopes the whole nerve trunk in a sheath from which septa are sent in dividing the nerve trunk into bundles. The nerve fibres do not branch or communicate with one another throughout the whole length of their course. By appropriate straining and examination they may be shown to have the structure represented in the accompanying illustrations (Figs. 107, 108).

At intervals there are constrictions of the fibre, which are termed the *nodes of Ranvier*. At the nodes the outer thin sheath of the fibre, known as the *neurilemma*,[1] is constricted, and the inner coat (*medullary sheath*), which is thick and consists of soft fatty material, is wanting. Here, where the medullary sheath is discontinuous, there may be made out a thin central fibre passing without interruption through the node. This thin fibre is termed the *axis cylinder;* when the medullary sheath is dissolved away by treatment with ether, it may be made out passing continuously from node to node throughout the length of the fibre.

The axis cylinder is the essential part of the nerve fibre, and the other coats are protecting sheaths for it. It begins as a process of a nerve cell, and pursues an uninterrupted course from the nerve cell to the nerve termination throughout the entire length of the nerve fibre. That the neurilemma or primitive sheath and the medullary sheath are accessory parts only, is shown by the fact that each is absent in certain situations, while the axis cylinder is never wanting. Thus, in the spinal cord and brain, where the nerve fibre is protected by other means, and where individual nerve fibres never run alone as they do in the terminal branchings of the peripheral nerves, the outer sheath is not required, and hence is absent. Again, in the sympathetic system, the medullary sheath is but feebly developed, and is often absent, giving rise to what are termed

[1] Also called the *primitive sheath* or *sheath of Schwann;* beneath this sheath cell nuclei are placed at intervals. These nuclei are best shown by straining with hæmatoxylin after treating with acetic acid.

non-medullated fibres (see Fig. 108), the usual variety of nerve fibre being called *medullated fibre.*

The nerve cells from which the nerve fibres arise vary greatly in appearance in different parts of the nervous system.

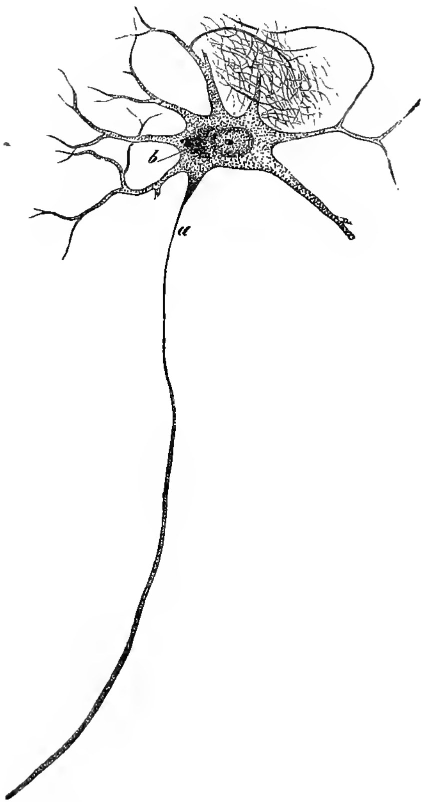

FIG. 109.—Multipolar nerve cell from anterior horn of spinal cord, human. (Gerlach.) *a*, axis-cylinder or nerve-fibre process; *b*, pigment.

Some are very large with a large clear spheroidal nucleus containing a nucleolus, while others are very small. They are classified, according to the number of processes which they

give off, into unipolar, bipolar, and multipolar. By far the larger number are multipolar, as this is the chief type found in the brain and spinal cord;[1] there are in this type a large number of processes, one of which becomes an axis cylinder of a nerve fibre, while the others branch into fine fibrils termed *dendrons* (see Fig. 109). Bipolar and unipolar nerve cells are chiefly found in the ganglia of the posterior roots of the spinal nerves. The nerve fibre of one nerve cell never communicates directly with another nerve cell, but breaks up into branches which interlace with the dendrons of that cell. The fibres of peripheral nerves communicate with their nerve cell at the central end; in the case of the afferent fibres this nerve cell is situated in the ganglion of the posterior root; in the case of the efferent fibres it is placed in the anterior cornu of the grey matter of the spinal cord. At the periphery these fibres terminate, either in ramifications formed by subdivision called plexuses, or in special end organs. Plexiform terminations are found in the cornea, in involuntary muscle and in certain glands. Special end organs are found in voluntary muscle, tendon, and skin; some of these are shown in the diagrams (Figs. 110, 111).

In certain cases, such as the tactile corpuscles in the skin, a nerve impulse originates in these end organs, and travelling towards the central nervous system gives rise to a sensation when it arrives there;[2] and in other cases a nerve impulse arriving at the end organ from the central nervous system starts cell activity there. For example, on arriving at a muscular end plate (see Fig. 111) a nerve impulse gives rise to contraction of the muscle fibre. The life of a nerve fibre depends upon its connection with the nerve cell to which it belongs; when severed from this the fibre undergoes certain changes which are spoken of as nerve degeneration. Only the part of the fibre which is cut off from the nerve cell undergoes these changes, the part still in connection remains unchanged

[1] The cells here are further classified according to their shape, *e.g.* the pyramidal cells of the cerebral cortex, and the pear-shaped cells of Purkinje in the cerebellum.

[2] The specialized nerve terminations in the organs of special sense, such as the eye and ear (see p. 245), may be regarded as such end organs in which nerve impulses arise giving origin in the brain to special sensations.

in its structure. This gives an important method of investigating the connections and course of nerve fibres, especially in the brain and cord. By its means tracts have been discovered in the spinal cord, for the fibres of the white matter do not run indiscriminately, but those with nerve cells situated above lie in one part, and those with nerve cells below lie in a different part. Hence some tracts of the white matter degenerate below

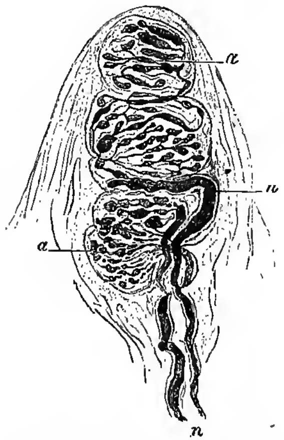

FIG. 110.—Tactile corpuscle within a papilla of the skin of the hand, stained with chloride of gold. (Ranvier.)
n, two nerve fibres passing to the corpuscle; *a*, *a*, varicose ramifications of the axis cylinders within the corpuscle.

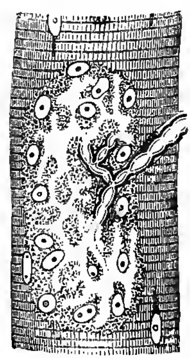

FIG. 111.—Nerve-ending in muscular fibre of a lizard (Lacerta viridis). (Kühne.)

(*descending tracts*), after section at any level, while other tracts degenerate above (*ascending tracts*). In this manner the ascending and descending tracts shown in Fig. 105 have been discovered.

The nerve fibres of the sympathetic system have their nerve cells in the ganglia of the sympathetic chain, and with these nerve cells fibres from the spinal cord communicate.

In general terms, then, the nervous system may be spoken of as an exceedingly complex meshwork of nerve cells, nerve

fibres, and nerve endings, in close communication with one another, and capable of affecting one another, and calling one another into activity. By communicating fibres all the different parts of the brain and spinal cord are, as it were, put in touch with one another; and there are usually several paths of nervous communication between any two given points, so that when one is broken down from any cause another may be used. At different points, nerves containing immense numbers or fibres pass off to all the peripheral parts to supply communication between the central nervous system and all the other parts of the body; some of these carry messages from the centre (efferent fibres), while others carry messages to the centre (afferent fibres). In addition, there are special nerves, capable of being rendered active by light, sound, etc., which convey impressions to the brain of what is going on in the outside world, and give rise to actions in the nervous system, which in turn are resolved into actions upon the other tissues.

The nerve cells are not arranged indiscriminately in the brain and cord, but those cells which carry out a common purpose are placed close together. A collection of nerve cells which possess a common purpose is termed a nerve centre. Such nerve centres are found in the different parts of the cord, medulla oblongata, and brain. The centres in the cord preside over the muscular movements, and are capable of carrying out quite complicated movements without assistance from the brain. This is especially the case in lower types of vertebrates, such as the frog; in the mammalia generally, and in man, these spinal centres are much less independent, and are completely under the control of the more highly developed brain.

The simplest form of a complete nervous action is what is termed a *reflex act.* In this an afferent impulse starting at the termination of an afferent nerve fibre passes up to the nerve centre and affects a nerve cell there; this in turn affects another nerve cell connected with an efferent fibre, and a nerve impulse travels down the efferent fibre, and shows itself by some action in the tissue to which this efferent fibre

passes. For example, irritation of the skin, by pricking with a sharp instrument, or by contact with a drop of acid, may stimulate sensory nerve endings in the skin, thus starting nerve impulses, in the afferent fibres attached to these nerve endings, which reach the nerve centre in the spinal cord; these next stimulate motor nerve cells and start efferent impulses down the fibres belonging to these cells which reach motor end plates in voluntary muscles and cause contraction and muscular movements.

Such reflex movements may be carried out by the nerve centres in the spinal cord without at all affecting the brain, and indeed can take place after the brain has been removed, or after the cord has been cut across and thus removed from the influence of the brain. Injuries to the spinal cord which practically amount to separation from the brain are often observed in man as the result of accident or disease, and it is then seen that although the muscles of the part of the body below the injury are no longer under the control of the will, they can be moved when the skin of the part is irritated. Such movements are reflex in character, and the centre for the reflex lies in the spinal cord; the brain is not affected by them, and the patient is not conscious either of the irritation of the skin or of the muscular movements, except by seeing them. Suppose, for example, the spinal cord is injured in the dorsal region so as to be no longer capable of transmitting nerve impulses up or down; then the legs become paralyzed, the patient can neither move them voluntarily, nor is any sensation felt as a result of any form of stimulation of the skin. In the lower animals, when the skin is irritated after such an injury, the lower limb is violently withdrawn, although the animal betrays no sign of a sensation. In man, on the other hand, the reflexes as well as sensation are abolished, and there is no movement of the limb on irritation of the skin supplied with nerve fibres from below the lesion.

It is in cold-blooded animals, such as the frog, that the cord is most perfect as a reflex centre. When the head of a frog is cut off, or its brain destroyed by pithing, the remainder of the animal is still capable of carrying out

most involved and complicated co-ordinated movements. If it be hung from a support, and a small piece of paper moistened with acid be applied to one flank, or to the abdomen, there is, after a pause, a movement of the leg obviously intended to stroke the irritated spot. If the leg of the same side be held and prevented from carrying out this purpose, then after a longer pause, there is a movement of the opposite leg, likewise designed to remove the source of irritation. If the piece of paper be applied to the back of the thigh, the muscular movement is of quite a different type, but designed also to brush the irritated spot. The movements are so purposeful as to suggest that they are directed by an intelligent reasoning cause, and there is no doubt that the nerve centres in the cord of such an animal act as subsidiary brains, and that although the frog as an individual is dead, yet there remains a nervous mechanism to all tests as intelligent as the entire nervous system of an animal of a somewhat lower type. Such an amount of independent action is not found in the spinal cord in warm-blooded animals, where these centres become more subsidiary to the chief centres in the brain. In warm-blooded animals the chief centre for voluntary co-ordination of complicated movements lies in the cerebellum, and when this is removed or injured by disease it is found that co-ordination becomes exceedingly faulty.

The functions of the different parts of the brain, in so far as they are yet known to us, have been made out in part from the study of disease in man, and in part from experimental removal in animals.

The office of the cerebral hemispheres as a whole is to receive nerve impulses from sensory fibres, which awaken what is termed perception, and give rise to varied sensations. As a result of these sensations, efferent voluntary impulses may be sent out from the cells of the cerebrum, and give rise to movements; or contrariwise nerve impulses may be sent out to stop or *inhibit* movements which would naturally take place in a purely reflex manner but for the restraining and guiding influence of the cerebral centres. For this restraining and guiding activity of the nerve cells of the cerebrum, many terms

are used in popular language, such as the intelligence, will, and judgment.[1] When the cerebral hemispheres are removed completely, the animal loses all this intelligence and guiding power. It is, like a ship without a rudder, completely at the mercy of all those influences which play upon it from the outer world. Each stimulus that reaches it gives rise to a certain response, just as if the animal were a piece of complicated but unintelligent mechanism. In the case of most warm-blooded animals, death soon follows complete removal of the cerebral hemispheres; but, in the frog, removal is not followed by death for a long time, if only the animal be kept moist. Such an animal, to casual observation, appears to differ little from a normal frog; it sits in a normal manner, and moves when irritated in any way. If placed on its back, it at once turns over into the natural position. If thrown into a vessel containing water, it swims in a regular fashion till it reaches the side of the vessel, and then, if possible, will crawl up this and perch passively on the top until it is again disturbed. If placed on a board which is slowly inclined, it does not slide off as the inclination is increased, but balances itself and crawls up the board, to perch in a more comfortable position on the top as the inclination is increased. If placed in front of an opaque obstacle and stimulated to jump, it springs to one side so as to avoid the obstacle. If stroked along the flanks, it croaks regularly. In fact, the animal is capable of carrying out the most complicated acts in a perfectly natural manner. *But it is merely an automaton*, all these things are performed mechanically, and with a stimulus definite in amount and kind, it is perfectly settled what the frog will do; there is but one answer to each stimulus. It never does anything *voluntarily*. It never moves of its own accord, but sits continually in the same spot and attitude unless stimulated from without. It takes no food,

[1] That the case is much the same in mammals is shown by the fact that serious injury to large areas of the cerebral cortex by operation leads to an idiotic condition of the animal, as is also the case when the blood-supply to the hemispheres, and hence their functional activity is interfered with. Again, in the case of man, want of development or insufficient development of the cerebral hemispheres causes idiotcy, and among different races of men, the grade of intelligence varies directly with the development of the cerebral hemispheres.

seems to have no sensations, and if undisturbed will die and dry up in the same exact position. All its responses to stimuli are definitely measured out so that a certain strength of stimulus gives a certain effect, there is no inhibition of movement or origination of movement by a reasoning centre. Swimming is caused by the afferent nervous impulses started by contact with the water, and will go on automatically till the animal reaches the edge or until it sinks exhausted to the bottom; the movements are uncontrolled. Again, when the flanks are stroked, the animal cannot decide to croak or not croak like a complete frog, but must croak automatically and in measured degree each time it is stimulated.

Similar experiments have been performed on the pigeon with like results; the animal, when undisturbed, sits as if asleep; but, when disturbed, can walk, fly, perch, and balance itself in a normal manner. It never takes food voluntarily, but swallows mechanically when food is placed at the back of the throat, and may be kept alive in this fashion for a long time.

It has already been mentioned that there is localization of function in different parts of the cortex of the cerebral hemispheres, and that the cortex around the fissure of Rolando governs the voluntary movements of the muscles of the trunk and limbs. It has further been discovered that certain other portions of the cortex are concerned in special sensations and special movements. These areas are shown in the accompanying diagram (Fig. 112), and have been localized by observing the effects of disease or injury upon these parts, and by experimental stimulation or removal of these parts of the cortex in animals. The part marked "lips and tongue" is concerned in controlling the movements of the muscles of the lips and tongue, and of regulating speech. Injury to this part causes inco-ordination of speech and inability either to *recollect*, or it may be to *say* certain words, a condition which is termed *aphasia*. This part of the cerebral cortex is hence termed occasionally the "speech centre." It is usually the left side of the brain which normally exercises this control; but in the event of permanent injury to this portion of the cortex on the left side, the right side after a time takes up the work, and the aphasia disappears.

Certain important nerve centres lie in the *spinal bulb* or *medulla oblongata*, and regulate the discharge of nerve impulses which are essential to the life of the animal. For example, the *respiratory centre* is situated here which regulates respiration. If the medulla be destroyed in the region of this centre, respiration ceases, and the animal promptly dies of suffocation or asphyxia. The afferent impulses arrive chiefly by the

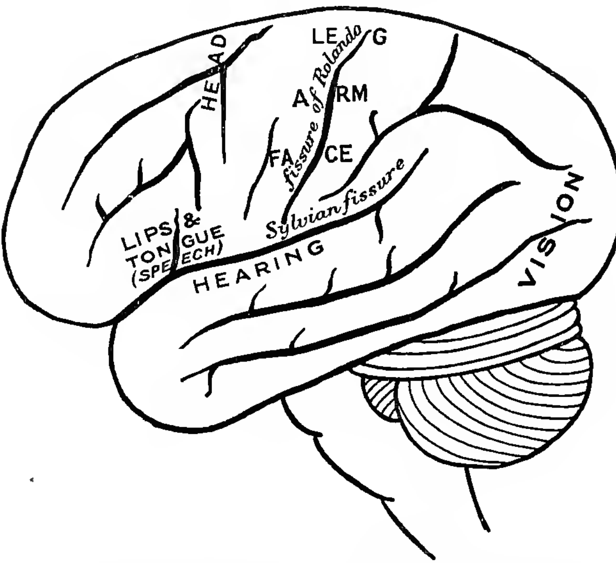

FIG. 112.—Diagram of the external surface of the brain seen from the left side; to indicate the position of the chief centres of localization.

vagus, and the efferent impulses are sent out along the phrenic nerves which supply the diaphragm, and the intercostal nerves which supply the intercostal muscles. The centre is acted upon in two chief ways: first, *chemically*, by the nature of the blood circulating through it, for when this is poor in oxygen the cells of the respiratory centre are stimulated to greater activity, and the rhythm of respiration is quickened; and secondly, the centre is stimulated by the number and strength

of the afferent nerve impulses reaching it. When the respiratory efforts are artificially increased the nerve impulses reaching the centre become feebler, and the centre acts less energetically; on the other hand, diminished respiration, or suspended respiration, for a short time strengthens the afferent impulses sent to the centre, and the desire to breathe, and to breathe strongly, becomes imperative. The respiratory centre is also affected, and the rhythm changed by nervous impulses reaching the centre along various other channels. Thus, violent emotions alter the respiration, and again a plunge into cold water will awaken sensory impulses from the stimulation of the skin, which affect the respiratory centre and change the rhythm. Quiet normal respiration is, however, brought about by an automatically repeated reflex, which is regularly discharged from the respiratory centre, and the variations in rhythm are due to *extra* afferent impulses arising from temporary causes.

Near the respiratory centre lies also the important vaso-motor centre which controls the tonicity of the small blood-vessels and so the distribution of the blood-stream. Here, also, are situated the cardiac centres, which control the rate of the heart-beat. Other centres are situated in the medulla, which control the reflexes for the winking or closing of the eyelids, which preserves the surface of the eyeball clean; which control reflexly the diameter of the pupil of the eye, and so regulate the amount of light entering; which control the reflex acts of swallowing, coughing, sneezing, secretion of saliva, vomiting, etc. It must not be understood, however, that groups of nerve cells corresponding to these centres have been demonstrated, it is merely known that the medulla is the part of the central nervous system which regulates these reflex acts.

To sum up, then, the nervous system is an exceedingly complex network of nerve cells, nerve fibres, and nerve endings. The nerve cells are situated centrally, and the nerve endings peripherally, and the two are connected by nerve fibres passing between centre and periphery. Further, the nerve cells in the different parts of the central system are connected together in a most complex fashion, by nerve fibres running from one part to another, and setting the whole in close communication.

In the spinal cord are nerve centres, which are capable of controlling complicated muscular movements, and these are under the control of the nerve cells in the cerebral cortex, by which they may either be set in motion or inhibited, *i.e.* put out of action. In the medulla (that part joining brain and cord) lie other centres which guide the rhythm of heart-beat and respiration as well as centres for carrying out other important work. In the cerebellar cortex lie intermediate cell stations which govern the co-ordination of voluntary movements, and in the cerebral cortex lie the master cells, which are so affected by the sensory impulses coming to them as to give rise, in some way unknown to us, to consciousness, will, judgment, intelligence, and memory, and have the power of sending out in reply different impulses which originate the acts of the animal.

CHAPTER XII.

THE SENSES.

OUR sensations are awakened by the stimulation of nerve centres in the brain by nerve impulses which start by the excitation of sensory nerve endings in the periphery and travel to the brain along sensory or afferent nerve fibres.

It is usual to divide sensations into two classes, although there is no very essential difference in kind corresponding to the classification. These two classes are *common* sensations and *special* sensations.

The first class includes those general sensations which cannot be localized accurately, such as fatigue, hunger, and thirst, as well as the sensations which give rise to coughing, vomiting, tingling, itching, and such like. All these sensations are referred to changes going on within the body.

The *muscular sense* is also usually classed as a common sensation. This sense gives an impression of the state of contraction of the skeletal muscles, and so enables the nervous system to regulate the degree of contraction which is necessary in the various groups of opposed muscles in carrying out complicated movements, such as walking, grasping, writing, etc. When the muscles contract against resistance the muscular sense also gives an idea of the amount of effort required, and it is this sense which we employ when we weigh bodies in the hand by movements of the forearm.[1] It is probable that the sensory nerve endings for the muscular sense lie in the muscles

[1] The muscular sense is much more delicate for this purpose than is the sense of pressure alone. Thus, while a difference of weight of one in thirty is easily appreciated by most people when movement of the forearm is allowed, it is scarcely possible to detect a difference of weight of less than one in eight when pressure on the palm is alone employed.

themselves, although it has been held by some that sensory nerve endings in the articular surfaces of the joints have a great deal to do with the sense of muscular effort, and with our appreciation of the weights of bodies.

Certain sensory nerves are, however, connected with specific kinds of sensations, which are produced by influences outside the body, and these sensations are termed special sensations. Usually five special senses are recognized, which are popularly known as the "*five senses;*" these are *touch*, *taste*, *smell*, *hearing*, and *sight.*

The sense of touch lies on the borderland between common and special sensations. It differs from the other four of the five senses in that it is not conveyed to the brain by any special nerve, but may be awakened by stimulation of any of the nerve endings of touch in connection with the cutaneous nerves. But it resembles the other four special sensations in that the cause producing it is referred, to somewhere and something outside the body, to an external cause. When we touch an object belonging to our surroundings, the sensation produced is known to be caused by something outside the body; just as when we see an object, we are aware that the visual sensation is awakened by something in the external world. But when our tooth aches, or when we are wearied, we feel that it is something connected with our body which is giving rise to the sensation.

We have to deal here more particularly with the special sensations and the apparatus by which they are evoked; we have to describe in outline the nature of the peripheral organs by means of which the various forms of energy reaching the body from the outer world are enabled to awaken sensory nerve impulses, which, travelling along definite paths to definite parts of the cerebrum, awaken in our consciousness each its own specific sensation.

There are one or two common properties of the special sensations which it may be well to state before passing to the description of each of the peripheral organs.

The nerve fibres which pass from a peripheral special sense organ are only capable of conveying to the consciousness one

specific kind of sensation. This is known as the law of *specific sensation.* Thus the optic nerves when stimulated in *any* manner only give rise in the consciousness to visual sensations, although the stimulation may be affected in various ways, such as ordinarily by the stimulation of the proper nerve endings of the optic nerves by light; pressure on the eyeball when the eyelids are closed;[1] application of the electric current, or severing the optic nerve. The same is true of each of the other specific sensations. For example, irritation of the mucous membrane of the nasal passages where the olfactory nerve endings lie, as by a catarrh or cold, may produce subjective sensations [2] of various smells.

Whatever part of a sensory nerve fibre be irritated, the sensation is always referred by the consciousness to the nerve ending in the periphery. Thus, after an amputation, when the cut ends of the nerve by reason of the irritation send impulses to the brain, these are felt as coming from the cut-off part, and the patient believes he feels pain in his fingers or toes as if these still formed part of his body. Again, if the elbow be immersed in a freezing mixture, the chill irritates the nerve trunks of the arm at the elbow; but the sensation experienced is not felt as coming from the elbow, a sensation of pain instead is felt which is referred to the finger-tips. The same kind of thing is felt when the ulnar nerve, which is almost subcutaneous at the elbow, is irritated by pressure or by a chance blow; the pricking sensation of "pins and needles" is then felt, not at the seat of irritation, but all the way down the forearm, where-ever the ulnar nerve has sensory endings, down to the finger-tips. Another example of the peripheral reference of sensation by the *sensorium* is the peculiar feeling experienced when a limb, as it is popularly termed, "*goes asleep.*" This is due to a slight continued pressure at any point on the nerve trunk, and not to anything at the periphery, although the tingling sensation is felt all over the distribution to the limb of the nerve pressed upon.

[1] The coloured images so produced are termed *phosphenes.*

[2] A *subjective* sensation is one produced in an abnormal fashion, giving rise to an impression of something in the outer world which has no existence in fact.

It has therefore to be borne constantly in mind that the seat of injury giving rise to a pain or other sensation may be either *central*, or *in the nerve trunk*, or *peripheral;* and still, in any of these cases, the nerve centres can only act and give rise to consciousness by sending in nerve impulses by the usual channels. Hence these are estimated as rising in the accustomed fashion, and so give rise in the consciousness, both to the specific sensation which is normally derived from impulses carried by that particular nerve route, and to the impression that the sensation has been awakened in a normal fashion by stimulation at the peripheral nerve endings.

The strength of sensations is not proportional directly to the strength of the physical stimulus, but varies as the logarithms[1] of the physical strengths; this is known as the *Weber-Feehner law.* It would never do, for example, if a light equivalent to 1000 candles in the physical intensity of its illumination produced one thousandfold the effect on the eye. In spite of the arrangements in the eye, which will subsequently be described, for shutting out excessive light, if such a condition of things existed, the bright light would only produce pain by excessive stimulus, and an illumination much short of the electric light, and far short of that of a bright sunny day, would absolutely blind us; either that or we could not see by the rushlight or starlight. But the relationship stated above of stimulation to sensation, tends to equalize sensations so that we can bear and appreciate both strong and weak stimuli. To a certain extent this toning down has to be paid for in inability to distinguish small variations in intensity, but the acuteness in this direction is sufficient for the ordinary wants of our life.

Although subjective sensations, as stated above, may be felt when the sensorium is divided from the peripheral nerve

[1] For those unacquainted with the nature of logarithms, a simpler statement of the law is that the change in magnitude of the sensation is proportional to percentage increase of the physical stimulus. Thus, a minute trace of difference in intensity of illumination can be made out by most persons between two lights of 100 candles and 101 candles respectively; now, to see such a difference with an illumination equal to 1000 candles, a light not of 1001 candles, but of 1010 candles, must be employed in comparison.

ending, or when a different part of the system than the nerve ending is irritated, still no *objective*[1] sensation can arise except by action in a normal manner of the proper kind of stimulus on the nerve endings, when these are in connection physiologically with the sensorium, and when all the entire physiological system (of nerve endings, connecting machinery of nerve fibres, and, it may be, intermediate nerve cells, and central nerve cells) is in working order.

For example, we can only see an object, which has a real existence apart from our fancy, and the existence of which can be corroborated by our other senses, when it is illuminated and casts an image on the retina at the back of the eyeball, thus awakening, in some unknown manner, nerve impulses in the fibres of the optic nerve, which travel finally to nerve cells in the occipital cortex of the cerebrum and set these in activity. Injury to any part of the physiological chain between retina and cerebral nerve cell may cause blindness. For example, the retina may be insensitive from some cause, and then no object can be seen, although the rest of the visual machinery may be quite perfect. Under such conditions, subjective sensations may indeed be produced by stimulation of the trunk of the optic nerve, but it cannot be stimulated by light, and no object in the external world can be discerned. Again, the eye may be uninjured, but the optic nerve or optic tract either cut across, or for some reason inoperative as a conductor, and the result is blindness. Finally, the cerebral area for vision (see Fig. 112) may be removed or diseased, and again the effect is the same.

Cutaneous Sensations.

The skin over the entire surface of the body is supplied with special sensory nerve endings. These nerve endings have many different forms in different regions of the skin, and also in different animals. One of the commonest forms is the *tactile corpuscle* (see Fig. 110, p. 236); these occur in immense numbers lying in rows immediately beneath the epidermis in the papillæ

[1] That is, a sensation caused by something with a real existence in the external world.

of the skin of the hand and foot. The tactile corpuscles are so called because they are supposed to be specially connected with the sense of touch, and certainly they are found in greatest abundance where the sense of touch is most acute. Still, there are other cutaneous sensations besides tactile sensation, and it is by no means clearly proved that the tactile corpuscles are not connected with the appreciation of these other sensations as much as with that of touch. Stimulation of the skin of any area by appropriate means may give rise to sensations, either of heat, of cold, of touch, or of pain, and there is a certain amount of evidence that these different sensations are produced by stimulation of different and specific nerve endings. For example, if a pointed rod of iron, which is either considerably hotter or considerably colder than the temperature of the body, be made to touch successively various points on the skin, it will be found that certain points called "heat points" exist, at which the hot point is much more acutely appreciated than at others; similarly there are other points at which the chilled point gives rise to a much more acute sensation of cold, and these "cold spots" do not coincide with the "heat spots." Hence the more acute perception does not depend solely on closeness to nerve endings, and there must be different nerve endings, some sensitive to a low and some to a high temperature. The perception of difference in temperature of the skin is often spoken of as the *temperature sense.* This by no means corresponds in its delicacy at different parts with that of the tactile sense, for tactile sensation is most acute at the tip of the tongue or the tips of the fingers; while the temperature sense is most acute upon the skin of the cheek, where the tactile sensation is not nearly so delicately developed. It must hence be admitted that the tactile sense and the temperature sense are distinct from each other, and are probably furnished by quite different sets of nerve endings and nerve fibres.

The delicacy of the sense of touch in different regions of the skin is estimated by the smallest distance apart at which two points are still felt as distinct. The testing is carried out by a pair of compasses so blunted as not to prick the skin or give rise to sensations of pain. It is found by this method that

the two points can still be appreciated as distinct when applied to the tip of the tongue at a distance apart of about 1 millimetre; at a less distance than this the points are no longer felt as two, and the person experimented upon is unable to say whether both points are applied to the skin or only one by the person carrying out the test. The tips of the fingers are next in order of delicacy; here the points can still be felt as discrete when only 2 millimetres apart. Other parts are less sensitive; for example—lip, 9 millimetres; front of forearm, 15 millimetres; forehead, 23 millimetres; back of hand, 30 millimetres; neck, back, arm, and thigh, 50–70 millimetres.

It is often erroneously stated that the sensation of touch is due to pressure on the sensory nerve endings in the skin; it would be much more correct to say that tactile sensation is due to variation in pressure upon these nerve endings. Constant *localized* pressure on the skin if excessive may give rise to a sensation of pain, but when not excessive does not give rise to tactile sensation if constantly applied. It is the sudden application of pressure or removal of pressure which affects the tactile nerve endings, and gives rise to the consciousness of something touching the part. This may be shown by laying a light object over the finger, which is kept *as still as possible* by resting it upon a table. After a short time the light object is scarcely felt to touch the finger, being only appreciated by the excessively slight involuntary movements and by the pulsations of the blood in the finger, which cause slight variations in pressure. If now the table be tapped, or the finger slightly moved, the object is felt much more distinctly. The same thing is experienced when the finger is dipped into a vessel of mercury. Here a very distinct sensation of touch is experienced where the surface of mercury touches in a ring around the finger, but little tactile sensation is awakened at the tip of the finger which is deepest in the mercury and has the most delicate development of the tactile sensation. This shows that it is not the pressure which arouses tactile sensation, for this is greatest at the finger-tip, but the rapid variation or oscillation in pressure which is greatest at the surface of the mercury where slight movements of the finger are continually alternately increasing and decreasing the pressure.

The *cutaneous* sensation of pain is probably specially localized in certain nerve endings and fibres like the sensations of heat and cold; for by a somewhat similar method to that which was employed for demonstrating "heat spots" and "cold spots" (namely, gently pricking the skin with a sharp point), it may be shown that certain localized points are much

more sensitive than others. At the same time, sensations of pain can be elicited from any point on the skin if the prick be severe enough, and also sensations of pain can be evoked by stimulation of nerves which do not supply cutaneous areas, and generally it seems to be the case that excessive stimulation of sensory nerve fibres anywhere is capable of awakening unpleasant sensation which is indefinitely and vaguely spoken of as pain.

There is no doubt that under the general title of pain many sensations are included together which are really distinct in character, and nearly any sensation which becomes sufficiently unpleasant is termed pain. For example, the pain of a headache is different in character from that of a toothache, and both are different from that of a burn. So that pain is not a specific sensation, but rather a term used to include certain somewhat closely allied forms of unpleasant irritation of the nervous system which usually arise from excessive stimulation of sensory nerves.

Taste and Smell.

The end organs of taste are situated chiefly on the tongue and soft palate. The terminal ramifications of the gustatory nerves pass to small ovoid clumps of cells which are known as "taste buds." The taste buds (see Fig. 113) are best seen in the depressions of the *circumvallate papillæ*, which are elevations arranged in a somewhat V-shaped manner at the base of the tongue, but they are also to be found all over the tongue, and upon the under surface of the soft palate, lying imbedded in the stratified epithelium. There are two kinds of cells found in each taste bud, viz. the *gustatory* cells, which are slender and fusiform, with a prominent nucleus and a long process at each end; and the *sustentacular* cells, which are elongated, flattened cells, pointed at their ends. The sustentacular cells lie between, and appear to support, the more delicate gustatory cells, and also form a cortical envelope round the outer part of the taste bulb. It is probable that the gustatory cells are those which are affected by the dissolved[1] sapid substance, and that this

[1] Only substances in solution affect the taste organs; thus, for example, quinine in powder is insoluble on the tongue and has scarcely any taste, although quinine in solution is intensely bitter.

alteration starts nerve impulses in the terminations of the gustatory nerves which ramify round the gustatory cells. The nerves of taste are the glosso-pharyngeal, which supplies the posterior part of the tongue and the soft palate, and the lingual branch of the fifth cranial nerve and the chorda tympani, which supply the anterior part of the tongue.[1] In some persons

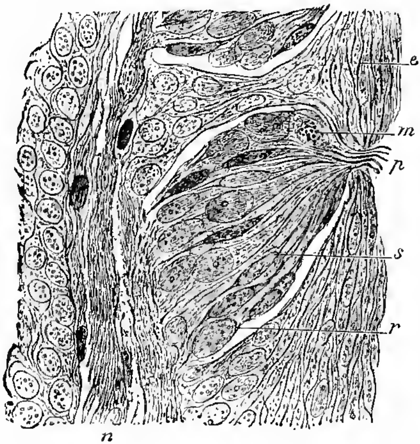

FIG. 113.—Section through the middle of a taste bud. (Ranvier.)
p, gustatory pore ; *s*, gustatory cell ; *r*, sustentacular cell ; *m*, lymph cell, containing fatty granules ; *e*, superficial cells of the stratified epithelium ; *n*, nerve fibres.

no taste sensations whatever can be appreciated on the tip of the tongue; while other individuals can only taste sweet substances in this region. The distribution of the different kinds of taste sensation is not uniform, and varies in different individuals. Most usually, sweet substances are tasted at the tip, and bitter substances at the back of the tongue; but some persons have both sweet and bitter tastes at the tip as well as at the base.

It is usual to state that there are four primitive types of taste sensation, viz. sweet, bitter, salt, and sour, but it is doubtful whether all possible

[1] It is probable that all gustatory fibres arise from the root of the fifth nerve, and join the glosso-pharyngeal and chorda tympani afterwards.

tastes can be referred to one of these four classes. Still, it is certain that the many different *flavours* which we experience in the different foods we eat are to a great extent due to a combination of olfactory sensations with gustatory sensations. It is a matter of common experience that when the olfactory mucous membrane is temporarily thrown out of working order by a severe cold in the head or nasal catarrh that we not only lose the sense of smell, but that the sense of taste also suffers, and we can no longer properly taste our food. This is due to the absence of the olfactory stimuli which previously formed a complex with the simpler sensations of taste, and gave rise to the flavour; in other words, we are unable to enjoy the flavour of our food in such a condition, because we cannot smell it as well as taste it.

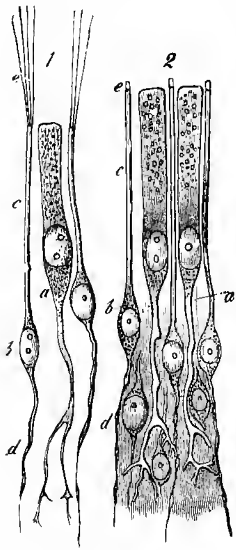

FIG. 114.—Cells and terminal nerve fibres of the olfactory region. (M. Schultze.) (Highly magnified.)

1, from the frog; 2, from man; *a*, epithelial cell, extending deeply into a ramified process; *b*, olfactory cells; *c*, their peripheral rods; *e*, their extremities, seen in 1 to be prolonged into fine hairs; *d*, their central filaments.

Sensations of smell arise from the stimulation of certain cells lying in the mucous membrane lining the upper portion of the nasal passages. There are two distinct kinds of epithelium found in the mucous membrane of the nasal passages; that lining the lower part (*Schneiderian* membrane) is ciliated like the epithelium of the trachea, while that of the upper part (*olfactory* membrane) is chiefly columnar and devoid of cilia. The air passing in and out to the lungs through the nasal passages passes over the part lined with ciliated epithelium, and this portion is not sensitive to smell. It is only when the molecules of the odoriferous substance are carried upwards by diffusion or air currents to the olfactory mucous membrane that the sense of smell is awakened. This takes place much more rapidly when inspiration is forced, and hence it is that we sniff or take in the air in little rapid inspiratory gusts when we attempt to detect a smell. The ultimate end organs of smell are probably spindle-shaped or bi-polar cells which lie

interposed between the columnar cells of the olfactory mucous membrane (see Fig. 114). These cells are termed *olfactory* cells, while the columnar cells which appear to serve to support them are called *sustentacular* cells. One process of the olfactory cell projects towards the free surface, and in some classes of animals ends in a number of minute hairs. The other process is long and delicate, somewhat resembling a non-medullated nerve fibre and becomes lost to view in a section of the membrane among the plexus of olfactory nerve fibres, lying immediately beneath the epithelium. The olfactory nerve fibres are non-medullated, they unite to form from twenty to thirty small nerves which pierce the cribriform plate of the ethmoid bone, and so enter the cranium and pass to the olfactory lobes.

HEARING.

The organ of hearing is usually described as consisting of three parts, viz. the external ear, the middle ear or *tympanum*, and the internal ear or *labyrinth*. The external and middle ear are accessory parts necessary for conveying the vibrations of the air, or sound waves, in a modified form to the internal ear in which are situated the terminations of the auditory nerve in a complicated structure known as the *organ of Corti*.

The *external* ear includes the *pinna*, which projects from the head and forms what is termed "the ear" in popular phraseology, and a passage (see Fig. 115) which leads from this towards the middle ear called the *external auditory meatus*. The pinna is composed of a shell of elastic cartilage covered with skin, which becomes pendulous at the lower part in the *lobule*, and contains there a certain amount of fat. In certain of the lower animals, the pinnæ can be moved about by attached muscles, and besides collecting the sound waves like an ear-trumpet, and thus making the hearing more acute, serve to give information of the direction from which a sound is coming by the direction of pointing in which it is most easily heard. But in man the pinna is rudimentary, and is more ornamental than useful; for persons who have been deprived of their ears have almost normal hearing; and also information is obtained as to the directions of sounds not by moving the ears, although vestiges of muscles still persist, but by moving the head.

The external auditory meatus is closed at its internal end (see Figs. 115,

117) by the *tympanic membrane*, or drum of the ear, which is placed obliquely across the meatus and forms part of the external wall of the cavity of the *tympanum*.

The middle chamber of the ear, called the *tympanum*, is a small irregular cavity in the substance of the temporal bone. It contains a chain of three small bones called the auditory ossicles (see Figs. 116, 117), which

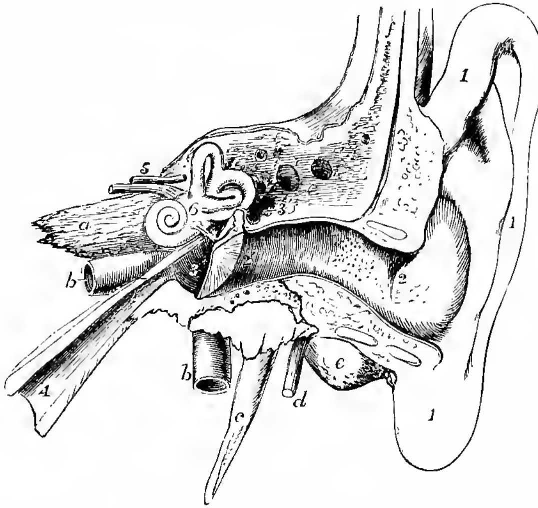

FIG. 115.—Diagrammatic view from before of the parts composing the organ of hearing of the left side. (After Arnold.)

The temporal bone of the left side, with the accompanying soft parts, has been detached from the head, and a section has been carried obliquely through it so as to remove the front of the meatus externus, half the tympanic membrane, and the upper and anterior wall of the tympanum and Eustachian tube. The meatus internus has also been opened, and the bony labyrinth exposed by the removal of the surrounding parts of the petrous bone. 1, the pinna and lobule; 2 to 2′, meatus externus; 2′, membrana tympani; 3, cavity of the tympanum; above 3, the chain of small bones; 3′, opening into the mastoid cells; 4, Eustachian tube; 5, meatus internus, containing the facial (uppermost) and auditory nerves; 6, placed on the vestibule of the labyrinth above the fenestra ovalis; *a*, apex of the petrous bone; *b*, internal carotid artery; *c*, styloid process; *d*, facial nerve issuing from the stylo-mastoid foramen; *e*, mastoid process; *f*, squamous part of the bone.

serve to convey with diminished amplitude and somewhat modified the vibrations of the tympanic membrane to the internal ear, where they produce an effect on the endings of the auditory nerve. The auditory ossicles are kept in position by certain slender ligaments attached to the bony walls of the tympanum, and their tension and that of the tympanic membrane is adjusted by certain tiny muscles. The most external of the three ossicles, which is termed the *malleus*, from a supposed resemblance to

a hammer, is attached by its longer limb to the tympanic membrane in an eccentric fashion so as to damp the vibrations which that membrane would tend to make most easily, and so renders it equally responsive to notes of all pitches. The intermediate ossicle, the *incus*, articulates by its shorter limb with the shorter limb of the malleus, and the extremity of its longer limb is attached by a ligament (in which a tiny ossicle is developed) to the head of the *stapes* (or stirrup ossicle). The base of the stapes, which is oval and surrounded by cartilage, is attached to a membrane closing an opening of an oval shape situated on the internal wall of the tympanum, called the

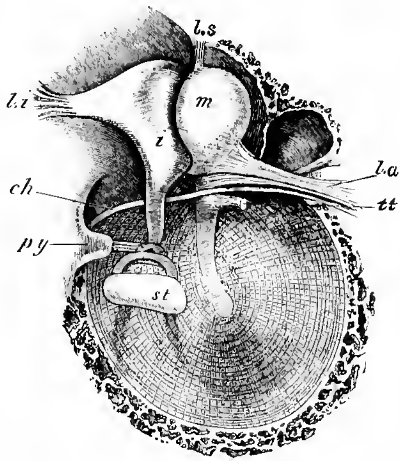

FIG. 116.—View of the left membrana tympani and auditory ossicles from the inner side, and somewhat from above (E. A. S.). $\frac{4}{1}$

m, malleus; *i*, incus; *st*, stapes; *py*, pyramid from which the tendon of the stapedius muscle is seen emerging; *t t*, tendon of the tensor tympani cut short near its insertion; *l.a*, anterior ligament of the malleus: the processus gracilis is concealed by the lower fibres of this ligament; *l.s*, superior ligament of the malleus; *l. i*, ligament of the incus; *ch*, chorda tympani nerve passing across the outer wall of the tympanum.

fenestra ovalis. The fenestra ovalis, as well as another opening on the internal wall of the tympanum, also covered by membrane and called the *fenestra rotunda*, communicates with the internal ear. The purpose of these two communications will be pointed out later.

The cavity of the middle ear is filled with air, and is in communication with the atmospheric air by means of a passage or tube called the *Eustachian tube*, which opens into the pharynx (see 4, Fig. 115). The purpose of the Eustachian tube is to keep the air at equal pressure on both sides of the tympanic membrane, so that this may be free to vibrate, and not be forced in or out by difference in air-pressure on its two surfaces. The tube

does not remain open always, but opens to adjust the pressure when any variation takes place; it opens for this reason during the act of swallowing.

The internal ear or labyrinth lies in a cavity of complicated shape hollowed out in the substance of the temporal bone, called the *osseous*

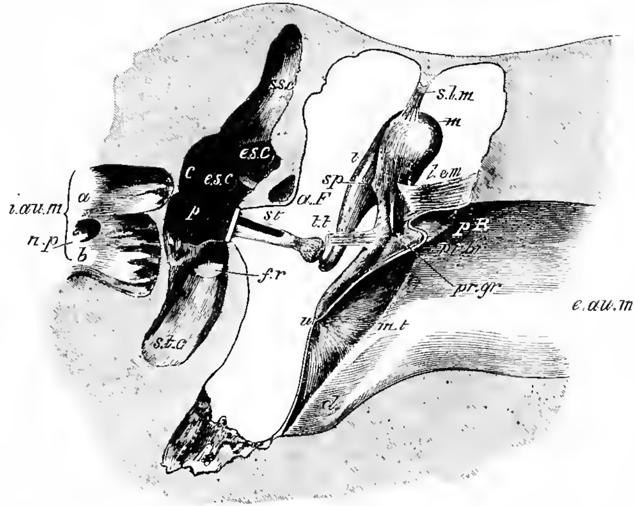

FIG. 117.—Profile view of the left membrana tympani and auditory ossicles from before and somewhat from above. Magnified four times. (E. A. S.)

The anterior half of the membrane has been cut away by an oblique slice. *m*, head of the malleus; *sp*, spur-like projection of the lower border of its articular surface; *pr. br*, its short process; *pr. gr*, root of processus gracilis, cut; *s.l.m*, suspensory ligament of the malleus; *l.e.m*, its external ligament; *t.t*, tendon of the tensor tympani, cut; *i*, incus, its long process; *st*, stapes in fenestra ovalis; *e.au.m*, external auditory meatus; *p.R*, notch of Rivinus; *m.t*, membrana tympani; *u*, its most depressed point or umbo; *d*, declivity at the extremity of the external meatus; *i.au.m*, internal auditory meatus; *a* and *b*, its upper and lower divisions for the corresponding parts of the auditory nerve; *n.p*, canal for the nerve to the ampulla of the posterior semicircular canal; *s.s.c*, ampullary end of the superior canal; *p*, ampullary opening of the posterior canal; *c*, common aperture of the superior and posterior canals; *e.s.c*, ampullary, and *e'.s.c*, non-ampullary end of the external canal; *s.t.c*, scala tympani cochleæ; *f.r*, fenestra rotunda, closed by its membrane; *a. F*, aqueduct of Fallopius.

labyrinth (see Fig. 119). Within the bony labyrinth lies a membranous tube of corresponding shape called the *membranous labyrinth* (see Fig. 118), which does not entirely fill the cavity in the bone, but leaves a space which is filled with a fluid called the *perilymph*.

The membranous labyrinth is likewise filled with fluid, which is termed the *endolymph*. The parts of the membranous labyrinth (see Fig. 118) are

the *utricle*, the three *semicircular canals*, the *saccule*, and the *cochlea*; and those of the osseous labyrinth are termed the *vestibule*, the *semicircular canals*, and the *cochlea*, of which the vestibule accommodates the saccule and utricle, and the semicircular canals and cochlea the correspondingly named membranous parts.

The vestibule is the central chamber of the labyrinth, and communicates in front with the cochlea and behind with the semicircular canals. Its outer wall, that next the tympanum, contains the fenestræ ovalis and rotunda mentioned above.

The osseous cochlea is a gradually tapering tube wound in a spiral of

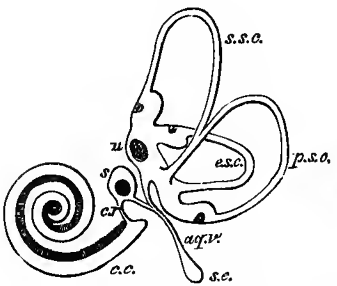

FIG. 118.—Plan of the right membranous labyrinth viewed from the mesial aspect. $\frac{2\frac{1}{2}}{1}$. (E. A. S.)

u., utricle, with its macula and the three semicircular canals with their ampullæ; *s.*, saccule; *aq.v.*, aquæductus vestibuli; *s.e.*, saccus endolymphaticus; *c.r.*, canalis reuniens; *c.c.*, canal of the cochlea.

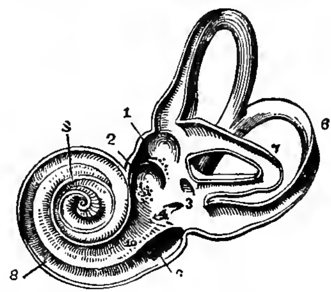

FIG. 119.—View of the interior of the left osseous labyrinth. (After Sommerring.)

The bony wall of the labyrinth is removed superiorly and externally. 1, fovea hemi-elliptica; 2, fovea hemisphærica; 3, common opening of the superior and posterior semicircular canals; 4, opening of the aqueduct of the vestibule; 5, the superior, 6, the posterior, and, 7, the external semicircular canals; 8, spiral tube of the cochlea; 9, scala tympani; 10, scala vestibuli.

two turns and three-quarters round a slender central pillar of bone, called the *modiolus*, from which a spirally wound lamina projects inwards, dividing the tube partially into two compartments. The membranous labyrinth lies within this spiral cavity, and between the membrane and the bony wall a space exists filled with perilymph. The membranous cochlea is divided into three distinct tubes (see Fig. 120) by two membranes. One of these membranes (the *basilar membrane*) stretches from the spiral lamina of bone mentioned above to the opposite wall of the bony cochlea, thus forming two divisions in the tube, called the *scala tympani* (beneath) and scala *vestibuli* (above). The second membrane (*Reissner's membrane*) meets the basilar membrane at an angle, and shuts off a small spiral chamber from the scala vestibuli, which is called *the canal* of the cochlea (see Figs. 120, 121).

It is within this canal of the cochlea that the *organ of Corti* is placed, resting upon the basilar membrane (see Fig. 121). The terminations of the

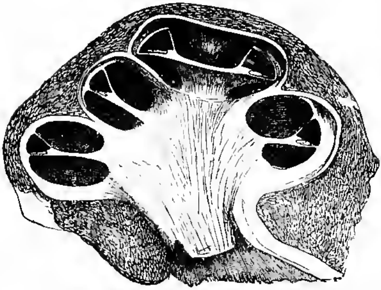

FIG. 120.—Vertical section of the cochlea of a calf. (Kölliker.)

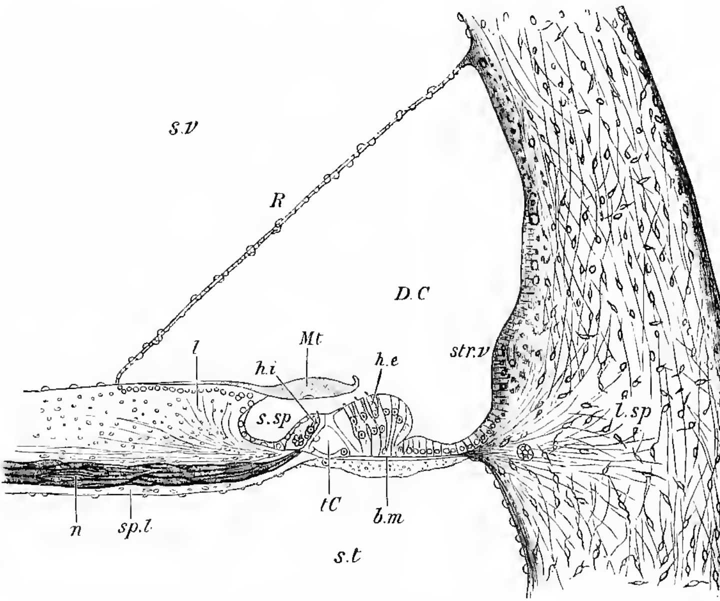

FIG. 121.—Vertical section of the first turn of the human cochlea. (G. Retzius.)

s.v., scala vestibuli; *s.t.*, scala tympani; *D.C.*, canal of the cochlea; *sp.l.*, spiral lamina; *n*, nerve fibres; *l.sp.*, spiral ligament; *str.v.*, stria vascularis; *s.sp.*, spiral groove; *R*, section of Reissner's membrane; *l*, limbus laminæ spiralis; *M.t.*, membrana tectoria; *t.C.*, tunnel of Corti; *b.m.*, basilar membrane; *h.i.*, *h.e.*, internal and external hair cells.

nerve fibres of the auditory nerve lie within this organ of Corti. The fibres course out in a radiating manner from the central modiolus to be distributed to the organ of Corti all along the length of the cochlea.

A complete description of the organ of Corti, which is very complex in its structure, cannot here be given; suffice it to say, that it consists of modified epithelial cells arranged in rows (see Fig. 121), and having an appearance of the general character of those found at the peripheral distribution of the nerves of special sense.[1] Certain of these cells are furnished with hair-like processes (auditory hairs), which project into the endolymph bathing the cells, and hence are brushed upon and easily affected by any movement of that fluid. The hair cells are placed in two columns, respectively internal and external, to two rows of cells called the rods of Corti, which incline towards each other and form the structure known as the *tunnel* of Corti. There is only one row of internal hair cells, but three or four rows are present in the external column. Over the organ of Corti there lies a pad of soft fibrillar tissue, which is called the *membrana tectoria;* during life this probably lies upon the hair cells and forms a kind of damper to prevent excessive disturbance of the auditory hairs.

We are now in a position to follow out the chain of changes which take place between the arrival of a sound wave at the membrana tympani and the arrival of the modified disturbance which it gives rise to at the organ of Corti.

A sound is due to disturbance propagated through the air in the form of waves of rarefaction and compression. As the waves of rarefaction and compression reach the membrana tympani this is alternately moved out and in by them at the same rate. Thus the membrane is set vibrating at the same rate as that at which the sound waves are produced. For a low-pitched note the sound waves are produced more slowly, there is a smaller number of vibrations per second, and for a high-pitched note the vibrations are more rapid. These variations in rate are faithfully copied by the movements of the membrana tympani. Also, the louder the note, the more excessive are the variations of rarefaction and compression, and so correspondingly more extensive are the movements of the membrane. The movements of the membrana tympani are communicated to the chain of ossicles in the middle ear, which move in unison with it. This movement of the chain of ossicles is not a vibration propagated through the substance of the ossicles, but a movement of each ossicle as a whole, the three bones forming a system of levers. The length of the arms of the levers is so adjusted that the extent of movement is diminished about one-third, so that the excursion of the stapes is only about two-thirds of that of the membrana tympani. There is also an arrangement at the articulation between malleus

[1] Compare the olfactory and gustatory cells already described, and also the rods and cones of the retina, with the hair cells of Corti's organ.

and incus, which prevents any excessive movement of the membrane, such as would be caused by the sound of an explosion, being communicated to the inner ear and damaging the delicate structures there.[1]

The movements of the stapes are communicated to the membrane covering the fenestra ovalis at its base. It will be remembered that the internal ear is completely filled with fluid, which is enclosed in a bony wall, except at two places, viz. the fenestra ovalis and the fenestra rotunda, where the bone is absent and the perilymph is separated from the tympanic cavity only by membrane. Now, when the fenestra ovalis membrane is pushed in by an inward movement of the stapes, the fenestra rotunda must be bulged out towards the tympanum, because the fluid in the internal ear is incompressible, and, *vice versâ*, when the membrane covering the fenestra ovalis is pulled outward by the stapes the membrane covering the fenestra rotunda must move inwards. It is thus easy to see why there must be two movable partitions between tympanum and labyrinth, for otherwise the vibration of membrana tympani and ossicles could not be communicated to the incompressible fluids of the labyrinth.

As the membranes covering the fenestra ovalis and fenestra rotunda thus move inward and outward in time to the swingings of the membrana tympani and ossicles, there is a surging in equal rhythm caused of the perilymph. This vibratory swinging of the perilymph is in turn communicated to the endolymph, and passes round the chambers of the cochlea, up the scala vestibuli, which lies nearer the fenestra ovalis, to the scala tampani which communicates at the head of the spiral with the scala vestibuli, and down this towards the fenestra rotunda. In its passage, along the cochlear chambers, this fluid vibration affects the fluid in the canal of the cochlea, disturbs the auditory hairs, and institutes changes in the cells of the organ of Corti, which are translated somehow into nerve impulses, and these, finally, travel up to the auditory centres in the brain and there awaken auditory sensations.

Deafness may arise from an incompetence at any part of this complicated system. It may be due to blocking of the external auditory meatus (for example, by impacted wax), preventing vibration of the tympanic membrane; it may be due to serious injury of the membrane itself, although a slight perforation is often present in persons with normal hearing; it may be due to permanent closure of the Eustachian tube, in which case there is no longer equal pressure on the two sides of the membrane, the middle ear becomes charged with exuded fluid, and vibration of the membrane and ossicles becomes impossible; it may

[1] For a complete account of the articulations and movements of the auditory ossicles, see Quain's "Anatomy," vol. iii. pt. iii. p. 95.

be due, though this form is rare, to disease in the auditory ossicles; it may be due to defects in the internal ear; and, finally, it may arise from disease, injury, or congenital defect in the cerebral cortex (see Fig. 112).

The *semicircular canals* (see Figs. 118, 119), although they are anatomically so closely associated in the internal ear with the auditory apparatus, have probably no connection with hearing, but are concerned with the sense of equilibrium and with the position (or rather changes in position) of the head in space. The canals are elliptical in shape, each forming about two-thirds of an ellipse, and the osseous canals open into the vestibule by *five* openings, for two join together at one end. The membranous canals are much more slender than the bony canals within which they lie, and the space between is filled with perilymph. Each membranous semicircular canal has a swelling near one end termed an ampulla, and on the inner surface of this there is a ridge called the crista acustica, upon which an epithelium containing cells with hair-like processes is placed. This epithelium is provided with nerve fibres derived from a portion of the auditory nerve, termed the *vestibular* nerve. Any motion of the fluid (endolymph) within the canal affects these hair-like processes, and gives rise to nerve impulses. The three canals are set in three planes at right angles to one another, and hence motion of the head cannot take place in any direction whatever without causing a movement of the endolymph certainly in one, and usually in two, of the three canals. The movements of the head thus give rise to sensations which supply a means of judging of the movements and aid in maintaining equilibrium. Disease of the canals, or experimental injury to them, causes injury to the sense of equilibrium, failure in balancing the body, and movements of rotation of the head corresponding to that canal which is injured.

SIGHT.[1]

In treating of vision it will be well in the first place to consider the structure of the eye; next, its action as an optical

[1] The student is strongly recommended to accompany this description by a dissection of an ox or pig's eye.

instrument; and, lastly, the nature of the peripheral nervous structures which are affected by the light. The eyeball lies in the forepart of the orbital cavity, where it is supported upon a soft circular cushion or pad of fat, and is surrounded by six muscles, by means of which it can be turned to a certain extent in various directions.

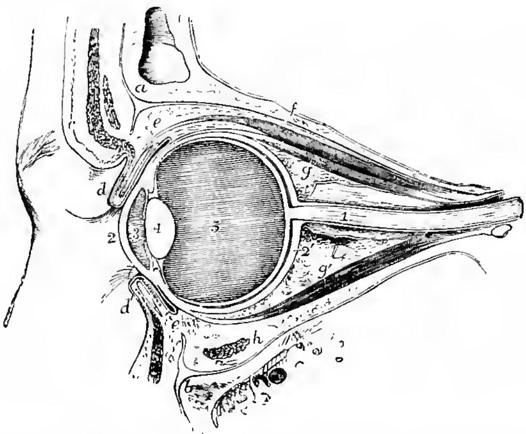

FIG. 122.—Section through the orbit and its contents. (Allen Thomson.)
a, frontal bone; *b*, superior maxillary bone; *c*, eyebrow; *d*, eyelids; *e*, conjunctiva; *f*, the muscle which raises the upper lid; *g* and *g′*, recti muscles; *h*, inferior oblique muscle cut across; 1, optic nerve; 2, cornea; 2′, sclerotic; 3, aqueous chamber; 4, crystalline lens; 5, vitreous chamber.

Four of these muscles run straight forward from the posterior part of the orbit to be inserted to the eyeball in front. They are hence called the recti muscles, and according to position are known as the superior, inferior, external, and internal rectus, respectively. Their action corresponds to these names; thus, the superior rectus raises, while the inferior depresses, the front part of the eyeball; the external rectus turns it outwards in front, and the internal turns it inwards.

The other two muscles are called the superior and inferior oblique, from their mode of attachment. The superior oblique muscle is attached to the posterior part of the orbit on the nasal side, and passing forward ends in a tendon, which loops round a kind of pulley of fibres attached to the frontal bone, and then passes backward and outward to become fixed to the eyeball at its outer and back portion. When this muscle contracts, it turns the front of the eyeball obliquely outward and downward. The

inferior oblique muscle arises from the lower and front part of the orbit on the nasal side, and passes obliquely backwards and outwards to be inserted on the posterior and outer part of the eyeball; by its contraction, the front of the eyeball is moved upward and outward. The muscles of the two eyeballs work together in most perfect co-ordination, so that both eyes are kept trained upon the same object at the same time, and by no effort of the will can one eyeball be moved without a corresponding movement of the other. This is necessary in order that images of objects may be cast upon corresponding points of the sensitive screens at the backs of the two eyeballs; otherwise, double vision is the result. This may be shown by artificially changing the direction of one eyeball by pressure upon it with the forefinger, when objects are at once seen double. In this complex co-ordination of the oculi-motor muscles, anatomically corresponding muscles in the two eyes do not always work together; for example, when the eyes are moved from side to side the external rectus of one eye contracts at the same time as the internal rectus of the other. In this manner the internal rectus of one eye and the external of the other are, so to speak, yoked together; on the other hand, the two superior recti muscles work together, and so do the two inferior recti muscles.

When the external surface of an eyeball is examined it is seen to be composed of segments of two spheres.[1] One of these spherical segments forms the middle portion of the front of the eyeball. It is by far the smaller of the two segments, forming only about one-fifth of the antero-posterior circumference of the eyeball. The smaller segment is called the *cornea*, and the larger segment the *sclerotic*. The cornea is transparent, and allows light to enter the eye; while the sclerotic is opaque, and allows no passage to the light.

The external surface of the cornea and the anterior portion of the sclerotic are covered by a delicate mucous membrane called the *conjunctiva*, which is also reflected all round over the internal surfaces of the eyelids. The conjunctiva is plentifully supplied with sensory nerve endings which make it very sensitive to any irritant, and is kept moist by the secretion of a special gland lying in the orbit called the *lacrymal* gland. When for any reason the secretion of this gland becomes too copious, the space between the eyeball and eyelids fills up and overflows, so giving rise to tears.

The cornea, to superficial examination, appears to be of different colours in different persons, but it is really quite transparent and colourless, as may be seen in dissecting an eye

[1] This may also be appreciated by closing the eye, placing a forefinger over the upper eyelid and moving it about, when the prominence of the anterior segment can be distinctly felt.

or by looking at the cornea of another person's eye from the the side. The colour is due to a pigmented screen, lying inside the eyeball behind the cornea, called the *iris*. In the middle of the iris there is a circular opening, through which the light enters the eye, called the *pupil*. No matter what be the colour of the eye, this central opening is always black (except in albinos),[1] because all the posterior part of the internal surface of the eyeball is lined by a black pigmented coat called the *choroid* coat, which reflects back no light, and so gives a black colour to the pupil.

At the back of the eyeball, a little to the nasal side of the pole of the posterior hemisphere, a thick nerve trunk, that of the *óptic* nerve, pierces the sclerotic coat and enters the eyeball. Its branches and endings are spread out over the posterior inner surface of the eyeball underlying the innermost of the coats of the eyeball, which is known as the *retina* and contains the elements which are sensitive to the light. The blood-vessels for the supply of the eyeball enter it along with the optic nerve, and ramify in the choroid coat. The structures lying within the eyeball may be seen by making a section from front to back with a sharp razor, and by dividing the sclerotic with sharp scissors circularly, parallel to, and somewhat behind the margin of the cornea.[2] The structures displayed in an antero-posterior section are figured in the accompanying illustration (Fig. 123). Behind the cornea lies the *anterior chamber of the eye*, which is filled with a thin watery fluid called the *aqueous* humour.

The anterior chamber is bounded posteriorly by the *crystalline lens*, and by the *suspensory ligament* which attaches the lens all round to processes (ciliary processes) which arise from the anterior margin of the choroid coat.

The crystalline lens (see Fig. 123) is a solid body composed of perfectly transparent fibres. It is a *convex* lens of which the convexity, and hence the focal length, can be altered, and its purpose is to focus images, on the posterior inner surface of the eyeball, of objects situated at variable distances in the

[1] In albinos the black pigment is absent from the choroid coat, and hence the pupil looks pink, because of the pink colour of the light reflected back through the pupil from the blood-vessels lying in the choroid.

[2] See Appendix.

field of view according as the attention is directed to these various objects.

Behind the lens lies the *posterior chamber* of the eye, which

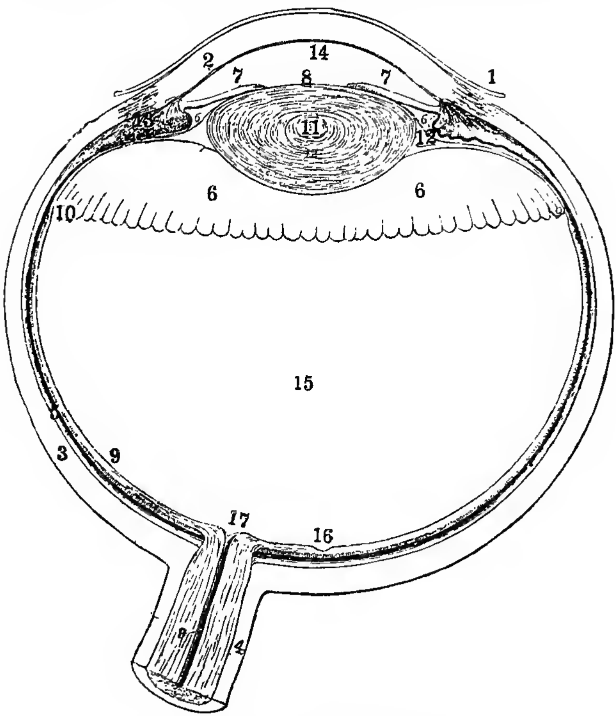

FIG. 123.—View of the human eye, divided horizontally through the middle. (Furneaux's "Physiology.")

1, conjunctiva; 2, cornea; 3, sclerotic; 4, sheath of the optic nerve; 5, choroid; 6, ciliary processes; 7, iris; 8, pupil; 9, retina; 10, anterior limit of the retina; 11, crystalline lens; 12, suspensory ligament; 13, ciliary muscle; 14, anterior chamber; 15, posterior chamber; 16, yellow spot; 17, blind spot.

is completely filled by a clear jelly-like mass called the *vitreous humour.*

The *iris* lies in the anterior chamber in front of the lens, and its variable central aperture (the pupil) lies opposite the central portion of the lens.

There is a circular muscle within the eyeball called the

ciliary muscle lying at the junction between cornea and sclerotic. Some of the fibres of this muscle are disposed circularly, running parallel to the junction of cornea and sclerotic; others run longitudinally, and are attached in front to the corneo-sclerotic junction and behind to the anterior margin of the choroid coat. When the longitudinal fibres contract they pull forward the anterior margin of the choroid coat, and so slacken the suspensory ligament of the lens which then, by virtue of its elasticity, takes a more convex form. Since the posterior surface of the lens must conform to the shape of the vitreous humour behind it, the alteration in shape takes place chiefly at the anterior surface. The purpose of this alteration in shape of the lens brought about by the action of the ciliary muscle is to focus objects upon the retina. When a near object is examined the lens is made more convex; when a distant object is looked at it becomes flatter.[1] The circular fibres of the ciliary muscle aid the longitudinal in pulling the choroid forward.

In the region of the eyeball behind the ciliary muscle and external to the viteous humour there are three coats in the wall of the eyeball. Of these, the inner is termed the *retina*, it contains the elements which are sensitive to the light; the middle coat is called the *choroid*, it contains cells which form black pigment, and in it run the blood-vessels of the eyeball; the external coat is the *sclerotic*, which is composed of tough white fibrous tissue.

The eye as an optical instrument bears a certain resemblance to a photographic camera. In both there is an inverted image formed of objects in the external world upon a sensitive screen placed at the back; but in the eye the image gives rise to nerve impulses which affect the consciousness, while in the photographic camera the effect produced by the light rays is made obvious by future chemical manipulation. In both

[1] In the case of an ordinary convex lens of glass, when the object is brought nearer, the image is formed farther off on the opposite side of the lens. But this would not be suitable in the eye, in which the screen or retina is placed at a constant distance; hence the lens is made *accommodating*, becoming more convex when the object is nearer, and so keeping it focussed upon the retina by bringing the rays to a focus in a shorter distance.

there is an internal black lining, the purpose of which is to prevent blurring of the image by internal reflection of the light. In both the images are focussed upon the screen at the back; but in the eye this focussing or *accommodation* is effected by a change in the focal length of the lens, while in the camera it is effected by changing the distance of the lens from the screen. Further, in the eye the whole chamber, by virtue of its shape, acts as a converging lens in focussing objects upon the retina, and the lens itself is chiefly of use as an adjusting mechanism—a kind of fine adjustment. Thus, there is convergence caused by the convex anterior surface of the cornea, and convergence by the refracting convex mass of the vitreous humour. In the photographer's camera, on the other hand, the chamber contains only air, and all the focussing is done by means of the lens. In both the amount of light which is allowed to enter is regulated by *stops* or *diaphragms*, according to the intensity of illumination of the objects of which images are to be cast upon the sensitive screens.

In the eye the adaptation of the size of the pupil, which forms the diaphragm of the eye, does not take place instantaneously, but follows somewhat slowly by reflex nervous action when the intensity of illumination of the retina is varied. It is for this reason that we are unable to see for a few moments when we suddenly leave a brilliantly illuminated room and pass out into a darkly lit space, until the pupil becomes widened to suit the dimmer light. Conversely, when we enter from comparative darkness to a place where there is a bright light we are at first dazzled by the excessive amount of light entering the eye, until the pupil contracts and relieves the sensitive retina. These changes are occasioned by two sets of muscle fibres in the iris; one set being arranged circularly around the pupil and the other disposed radially.

The retina or sensitive screen upon which inverted images of objects are focussed by the optical action of the refractive substances of the eyeball consists of eight different layers which are diagrammatically shown in the accompanying figure (Fig. 124).

Of these layers that called the layer of rods and cones is the one which is primarily affected by the light.[1] It lies

[1] This is shown by the fact that this is the only layer present in the *fovea centralis* (*vide infra*), which is the most sensitive part of the retina.

farthest removed from the entering light next the choroid coat, and is bound by certain cells containing pigment called the pigment cells.

The retina is not equally sensitive in all parts. Where the optic

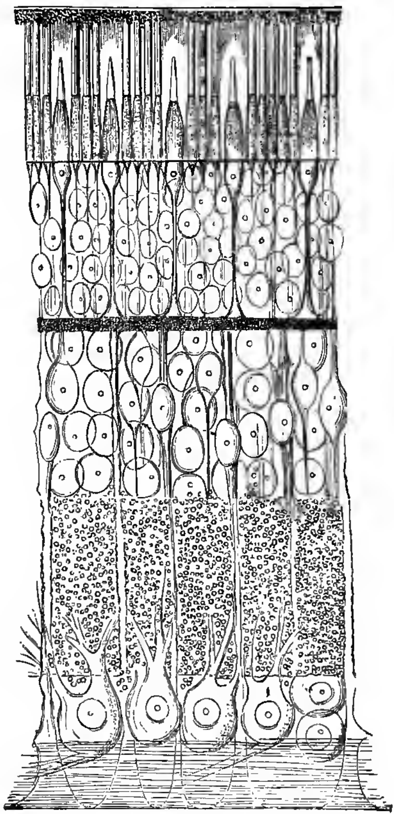

FIG. 124.—Diagrammatic section of the human retina. (Schultze.)

nerve enters, a little to the nasal side of the pole of the posterior hemisphere, the retinal elements are absent, and the branches of the optic nerve spread out in all directions to form a network. This region is called the "*blind spot*," and is quite

insensitive; so that when the image of an object falls upon it no visual sensation is produced. About a tenth of an inch to the temporal side of this there is a small yellow spot called the *macula lutea*, of slightly elliptical shape (see Fig. 125), which

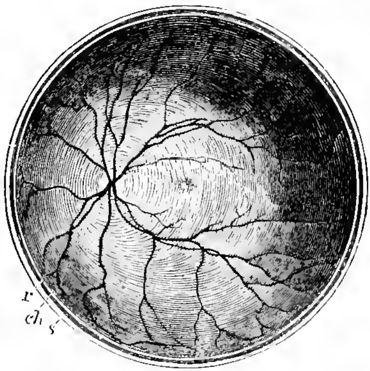

FIG. 125.—View of the posterior part of the retina.

A.—The posterior half of the retina of the left eye, viewed from before. (Henle.) Twice the natural size.

s, cut edge of the sclerotic; *ch*, choroid; *r*, retina: in the interior at the middle the macula lutea with the depression of the fovea centralis is represented by a slight oval shade; towards the left side the light spot indicates the colliculus or eminence at the entrance of the optic nerve, from the centre of which the arteria centralis is seen sending its branches into the retina, leaving the part occupied by the macula comparatively free.

has in its central part a slight depression called the *fovea centralis*. The fovea centralis lies at the opposite pole of the eyeball from the pupil, and is the part of the retina upon which vision is most acute. When the attention is directed to an object, the eyeballs are so turned that the image of it is focussed upon the fovea centralis and the parts of the macula lutea adjoining. Objects, of which the images are cast upon other parts of the retina, are only seen very indistinctly, and are more indistinct as their images fall more distant from the fovea centralis.

The existence of the blind spot may be easily demonstrated by making two round dots on a piece of white paper, each about one-tenth of an inch in diameter, and about two

inches apart, and then observing these two spots with each eye in succession, the other eye being closed in each case.

While observing with the right eye look steadily at the left-hand dot and move the sheet of paper nearer and farther alternately from the open eye. When the paper is near the eye both dots are easily visible, but at a certain distance the right-hand dot completely disappears and does not re-appear until the paper has been moved considerably farther from the eye. A similar result cannot be obtained in the case of the left-hand dot by looking at the right-hand dot with the right eye. A disappearance of the *left* dot can similarly be obtained in the *left* eye when the right dot is focussed upon the fovea, but not of the right dot when the left dot is so focussed. Remembering that the light rays cross in the eye before reaching the retina, and hence that the position of images is inverted, a little consideration will show that these experiments demonstrate that the blind spot lies to the nasal side of the fovea centralis.

The visual sensation outlasts in time the stimulation of the retina by the light. The sensation does not quite disappear until the lapse of about one-tenth of a second after the stimulation. Hence, when a light flashes more than ten times in a second, the flashes fuse into one another, and the sensation produced is a continuous light, but unsteady and flickering. If the flashes succeed one another at a rate of fifty to sixty per second the flickering sensation disappears and the flashes are fused into a steady light. This continuance of sensation after stimulation is the explanation of such familiar phenomena as the circle of fire caused by rotating a stick with a glowing end, the fusion of colours in the rotating colour top, and the fusion of the spokes of a rapidly rotating wheel.

We can distinguish many hues and shades of colour in the objects which we see, but all these varied colours only awaken three kinds of sensation.[1] Coloured light of any given wave-

[1] Rival theories have been advanced to explain the phenomena of colour vision; these theories are both exceedingly artificial and insufficient, and so an attempt has been made above to give an outline of a few of the principal facts.

length arouses all of these three sensations, but in very varying degree, and the sensation produced as a resultant varies with the comparative intensity of the three component sensations. The three primary sensations are each most strongly produced by red, green, and violet light respectively, and these are hence spoken of as primary colours. However, red light only awakens the red sensation in a preponderating degree; the other sensations are also produced, only much more feebly. So any tint is produced by certain fixed degrees of intensity of simultaneous stimulation of the three kinds, and any variation in the relative strengths of the three component stimuli will cause a corresponding variation in the tint. This can be experimentally shown by fusing together, so that they affect the same portion of the retina, coloured lights in varying intensity, as, for example, by casting them on the same surface, or by spinning them on a colour top.

The sensation produced by light of any given physical composition varies greatly with the condition at the time being of the visual apparatus; not only so, but the condition of the part of the retina immediately around the area stimulated has a profound effect on the sensation evoked.

The visual apparatus is easily fatigued, and while in a fatigued condition it reacts less easily than when in a fresh condition; again, it can be fatigued for one colour, and yet react normally to a colour for which it has not been fatigued.

If a bright white spot be looked upon for 10 to 20 seconds, and then the eyes be turned to a dull uniform grey background, or be closed, an image of the spot in black or duller colour, which is called a negative *after-image*, is seen on a brighter background. If a coloured spot be employed in the first case, an after-image of the complementary colour is seen—that is, an image which if used with the original would produce white as a result. Here the colour of light is changed by previous actions carried out upon the part of the visual apparatus causing the sensation—in other words, the sensation produced is shown by the experiment to vary altogether with the condition at the moment of the visual mechanism stimulated. Again, if a colour be viewed upon a background of its complementary colour, it

appears much brighter from what is called *simultaneous contrast*,[1] showing that the sensation is influenced by the condition of neighbouring parts of the visual apparatus.

The result of simultaneous contrast is beautifully shown by the experiment of Mayer, which consists in covering with tissue-paper a small piece of *grey* paper placed upon a coloured paper surface; the grey paper then appears coloured with a tint complementary to that of the colour upon which it is placed.

In some persons, who are said to be *colour blind*, the perception of colours is imperfect. Such persons usually have but two colour sensations, and derive all their sensations of tint from fusion of these two. In the commonest form of colour blindness, red and green appear alike, and a red cherry is of the same colour to such people as the leaves of the tree on which it grows; in other persons, the middle of the spectrum is of a neutral tint, and red and blue gradually fuse into each other. Unfortunately, such persons are always born colour blind, and so we cannot compare sensations with them, or else important facts concerning colour sensation might be discovered.

[1] *Successive contrast* is when a colour is viewed after its complementary colour; here again the colour is brighter, showing in a converse manner the same truth as after-images, that the effect depends upon the immediately previous history of the part stimulated: this is a contrast in time, while "simultaneous contrast" is a contrast in space.

APPENDIX OF PRACTICAL EXERCISES

1. Make dissections of the body of any small mammal, such as a rabbit, guinea-pig, white rat, or kitten.[1]

Fasten the animal upon its back, make an incision through the skin in the mid-line in front all the way down, and draw the skin aside. Cut through the abdominal wall in the mid-line and make a cross cut above, parallel to the ribs on each side.

Examine the abdominal viscera, and observe their position. If the animal has just been killed, note the peristaltic movements of the intestine, and start a contraction at any point by touching with the point of a knife. Observe the long pause (latent period) before the contraction commences. Examine the way in which the intestine is attached to the abdominal wall by the mesentery, and, if the animal has recently been fed on a fatty meal, look for the lacteals in it, filled with a milky fluid (chyle). Note the position of the various viscera as described in the text (pp. 87–95). Look for the pancreas lying in the loop of the duodenum. In a herbivorous animal this gland is diffuse and inconspicuous, but it is easily found in the carnivora. Pull the stomach to the right, and observe on the left side the spleen and its attachments. Look also for the opening of the small into the large intestine, and observe the cæcum and vermiform appendix, which are large in herbivora, but small in carnivora.

Next tie two ligatures around the œsophagus, a short distance apart, and cutting between the two ligatures, and then through the mesentery, remove the intestine down to the rectum, where two other ligatures are to be tied and cut between. Cut open the small intestine, and observe the velvety appearance of the inner surface caused by the projecting villi; look at it with a magnifying glass after washing it with water. Similarly examine the inner surfaces of the stomach and large intestine, and note that there are no villi on these surfaces. Note, in the case of the stomach, the thick glandular mucous membrane, which is often thrown into *rugæ*, or folds.

After the removal of the stomach and intestine, observe the position of the kidneys, and the small suprarenal bodies lying above them, and of the

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[1] The animal may be most painlessly killed by placing it under a glass bell jar or other cover with a piece of cotton wool soaked in chloroform. All the dissections described below can scarcely be made at one time, but can be made at intervals as opportunity offers.

liver. Remove the liver and the kidneys, and examine them. Note the lobes of the liver and the position of the gall-bladder. Observe the impressions on their surfaces, which correspond to the adjacent viscera. Observe how the vessels enter the gland, cut into it and examine the substance of it. Slice open one of the kidneys longitudinally, compare it with Fig. 98, p. 209, and read the description of its naked-eye appearance there given. Similarly cut open one of the suprarenal glands, and the spleen.

Examine the abdominal cavity after the removal of these organs; note the smooth lining, and search for the aorta and inferior vena cava, which will be found, if they have not been accidentally removed in the dissection, running down in front of and parallel to the vertebral column.

Next dissect the thorax, commencing by removing the front portion of the thoracic wall. In a small animal, the ribs can be cut through on each side with a strong pair of scissors, and the front parts of the ribs and the sternum completely removed. When the thorax is opened the lungs collapse and occupy a comparatively small volume; it must be remembered that when the thorax is complete they are distended, and occupy the greater part of the cavity.

Observe the position of the heart and the great vessels passing to and from it at its base; note the pericardium which encloses it, and then cut through this and expose the heart. In an animal which has just been killed, the heart may often be made to contract by pricking it with a sharp-pointed instrument. Look at the roots of the lungs and the vessels and bronchi constituting each. Feel the lung tissue, which gives a *crepitant* sensation to the fingers. Dissect up into the neck so as to expose the trachea and larynx. Find the œsophagus behind the trachea, and trace it through the thorax to the point at which it passes through the diaphragm. Examine the diaphragm lying between the thorax and abdomen, and note the shape of the central tendon. Try to find the places where the inferior vena cava and the aorta penetrate it, and trace these vessels up to the heart. Remove the trachea and lungs, tie a tube into the trachea, blow air into it, and show that the lungs become distended and greatly increased in volume.[1] Remove the heart and the roots of the great vessels attached to it. Examine its structure as far as is possible with a heart of such small size (see pp. 113–120).

Next remove the skin from the lower part of the animal and dissect one leg. Turn the animal back upwards, and examine the structure and arrangement of the muscles at the back of the thigh and leg. Separate the muscles on the back of the leg and search for the *sciatic* nerve, which will be found lying deep between two chief groups of muscles. It is in appearance a strong, white, rounded, glistening cord. Lay it bare in its whole length; observe that it gives off branches to the muscles of the back of the leg,

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[1] This is the reverse mode of distension to that which takes place during life, when the lungs are distended by diminution of pressure on their outer surfaces.

and near the knee divides into two chief branches, which go to supply the parts below the knee. Dissect the nerve upwards towards the spinal cord, and observe that it is derived from three or four nerves which unite to form what is known as the *sciatic plexus*.[1] Follow these nerves to the spinal cord, and note that a nerve trunk is in each case formed by the union of an *anterior* and a *posterior* root which arise separately from the side of the spinal cord. Cut a piece out of the sciatic nerve, tease it with needles, and note that it can be easily split up longitudinally, that is, in the direction in which the fibres run in it. The same thing may next be done with a piece of muscle.

Remove the skin from the back of the animal and from the back of the head by making a long incision in the middle line, and turning the skin outwards to each side. Clear the muscles away from the vertebral column in the back and neck, and then with a pair of bone forceps snip away the laminæ of the vertebræ so as to expose the spinal cord throughout its length.[2] Remove also the upper part of the cranium so as to expose the brain, and then study the naked-eye structure of the cerebro-spinal axis. Note the tough membrane (*dura mater*) which covers the brain and spinal cord; remove this and observe the *convolutions* and *sulci* on the surface of the brain. Note the blood-vessels which are carried by a thinner membrane coating the brain, termed the *pia mater*. Remove the brain and cord, commencing at the fore part of the brain. The cranial nerves must be cut through in order to do this, and also the spinal nerves. Note the thick optic nerves which meet to form the *optic chiasma*. Study the brain and cord with the aid of Chapter XI., and the figures given there. Note the manner in which the nerve roots arise from the brain and from the spinal cord. Cut a slice from the cerebral cortex and observe the white *medullary centre* underlying the grey *cortex;* slice deeper and expose the cavity or ventricle within the cerebrum; cut into the basal ganglia seen on the floor of this ventricle. Slice through the cerebellum at right angles to the direction of the convolutions, and observe again the cortex outside and medulla within, giving rise to the appearance known as the *arbor vitæ*.

Observe also the *pons Varolii* connecting the two cerebellar hemispheres; the *crura cerebri* conveying the fibres in two great masses from the cerebrum towards the cerebellum and cord, and the *medulla oblongata* or *spinal bulb* connecting brain and cord. Cut through the spinal cord at different levels, and note the grey matter in the centre surrounded by the white. Observe also the increased area of the grey matter at the enlarged parts of the cord opposite those portions where the nerves to the limbs are given off, because here more nerve cells are required; also the comparatively small grey area in the dorsal region, where the nerves given off are much smaller. Notice

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[1] Bone forceps or very strong scissors will be required in doing this to snip through the bones which conceal these nerve roots.

[2] This is a somewhat difficult dissection for a beginner, and requires the exercise of a good deal of patience.

also that the shape of the entire section and the contour of the grey matter vary in the different regions, thus making it easy to distinguish sections of cord from cervical, dorsal, and lumbar regions respectively.

Finally, clear away the flesh from about one or two of the joints, examine these, dislocate them and learn their construction.

2. Make a dissection of a frog. In a cold-blooded animal tissues remain alive for a longer time after the death of the animal than is the case with mammals, and hence many important physiological facts can be ascertained. A small depression may be seen behind the head, almost lying at the apex of an imaginary equilateral triangle with the line joining the two eyes as base. Insert a pin at this depression and pith the brain of the animal and its spinal cord, so killing it by destroying the nervous system.

Pin the animal out on its back upon a cork board, and remove the skin from the thorax and abdomen. Next remove the front of the thorax, taking care not to go too deep, so as to avoid injuring the heart which lies underneath. The heart is then exposed, and is seen beating within the pericardium. Carefully snip away the pericardium, and observe the beating of the heart; notice that the auricles beat first and then the ventricle, followed by a pause.[1] If the lung should happen to be distended, observe that it is of a much simpler type than in mammals, being simply an air sac on the wall of which blood-vessels ramify. Snip into the lung with scissors, and it at once collapses. Remove the skin from the posterior part of the body and look for the sciatic nerve at the back of the thigh. Expose the nerve for some distance, then pinch it with forceps, and note that the muscles at the back of the leg beneath the knee contract vigorously (mechanical stimulation); cut the nerve through with scissors below the point previously pinched, and note that the muscles again contract. Dissect out the corresponding nerve on the other side, tie it tightly near the upper end (the muscles contract); now cut it above the point at which it has been tied—no contraction takes place because the physiological continuity of the nerve has been interrupted. Cut the nerve below the point at which the ligature was tied, apply a crystal of salt to the cut end, and note that the muscles commence contracting and go on twitching, because the nerve is stimulated by the salt (chemical stimulation). Cut the nerve beneath the place at which the salt has acted upon it, and these twitchings cease. Hold a zinc and copper wire in contact with your fingers, and place the two wires across the nerve at a short distance apart; each time the nerve is touched by the wires, the muscles which it supplies contract (electrical stimulation).

3. Observe through the microscope the circulation of the blood in the thin web of the frog's foot, or in the tail of a tadpole, minnow, or other small fish. The foot should be tied or pinned so that the web is spread out over a round hole in a piece of cork board or wood, and then the preparation should be brought under the low power of the microscope. In the case of the tadpole, this may be wrapped round with wet filter-paper and then

[1] There is only one ventricle in the frog, instead of two as in mammals.

placed upon a microscope slide so that the tail lies under a low-power objective. Notice that the red blood corpuscles move rapidly down the central part of the vessel observed, while the white corpuscles roll sluggishly along the wall of the vessel. Bring a small artery into the field of view and observe the pulsatile flow, the beats of which correspond to the heart-beats.

4. Listen to the heart-sounds in another person by placing your ear opposite the proper part of the chest wall. At the same time, feel the pulse and note that it is synchronous with the beat of the heart. Count the pulse-beats per minute; ask the person to take a short run, then listen to the heart, and feel and count the pulse once more. Also count the number of respirations per minute, before and after a run, on another person who is not aware of what you are doing, and note the increase in rate.

5. Perform the experiment upon a long vein of the arm described on p. 112.

6. Place three fingers of one hand upon the radial artery at the wrist; the pulsations of the artery can be distinctly felt by all three fingers. Compress the artery strongly with the middle finger, and the pulse is now felt by the finger towards the upper arm, but not by the finger next the wrist, thus showing clearly that the pulse is propagated from the heart.

7. Obtain an uninjured sheep's heart from a butcher, and make the following experiment to demonstrate the action of the semilunar valves. Take two glass tubes, about half an inch in diameter and each about eighteen inches long,[1] and tie one securely into the aorta and the other into one of the pulmonary veins, and afterwards tie the other pulmonary veins. Or, one tube may be tied into the pulmonary artery and the other into one of the *venæ cavæ*, the other vein being tied up as before. Now pour water into the tube attached to the vein, both tubes being held vertically, and alternately compress and relax the ventricles by squeezing with the hand. The water falls in the tube which is tied in the vein, and rises in the tube tied in the artery, being upheld during the intervals of relaxation by the closed semilunar valves. This illustrates the action of these valves during life.

8. Carry out with the same heart the dissections described on pp. 115–120.

9. Make, and examine, the histological preparations of blood corpuscles described on p. 121.

10. Instruct a butcher to draw off a quantity of blood into a vessel when killing an animal, and then later study the character of the contents of this vessel. The clot is red outside, but black when cut into; also, when the cut surface is exposed for some time to the air it turns red (see p. 187).

11. Obtain also some whipped blood, and perform the experiments indicated on p. 187.

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[1] The tubes should be slightly pulled out in a blow-pipe flame close to one end, so as to form a shoulder round which the ligature can be firmly applied.

12. Pour off some of the serum which has exuded from the clot obtained in experiment 10, and dilute it with about three times its volume of water. With the fluid so obtained perform the following tests, which are characteristic tests for proteids :—

(*a*) Add a *trace* of acetic acid, and heat; before boiling commences a white *coagulum* is thrown down. This is what happens to the white of egg when an egg is boiled, and is termed *heat coagulation*.

(*b*) Add a single drop of a dilute solution of copper sulphate, and afterwards excess of caustic potash, and the solution will turn a violet colour (Biuret test).

(*c*) Add strong nitric acid; the solution turns yellow and gives a white precipitate which turns yellow on boiling. Allow the solution to cool, and then add excess of ammonia, when the solution will turn orange-coloured (xantho-proteic test).

(*d*) Add excess of alcohol and a white precipitate will be thrown down.

13. If possible, carry out the separations described on p. 128.

14. Make some starch paste by powdering a small quantity of starch[1] and then boiling with water. If a drop of this paste be added to a drop of a dilute solution of iodine, a deep blue colour is the result. Now add some saliva from the mouth to a quantity of this starch paste, keep the mixture warm, but not too hot,[2] and test, by means of the iodine solution, drops taken from it from time to time. It will be found that the blue coloration after a time no longer appears, and finally, after a transitory stage in which a red is obtained, no coloration whatever is produced by the iodine. This experiment shows that the starch has been converted into something else by the action of the saliva, and if some of the solution be now taken and tested by adding a few drops of copper sulphate and excess of caustic potash it will be found that the copper salt is reduced. In fact, as can be shown by more elaborate experiments, a reducing sugar called *maltose*, mixed with certain bodies intermediate in chemical nature between starches and sugars, and called *dextrins*, has been produced by the action of the saliva on the starch (see p. 146).

15. Feed an animal on food containing fat, such as fat meat, and kill it after an interval of about five hours. Open the abdomen and observe the milky lacteals in the mesentery. Open the thorax and search for the thoracic duct, which is charged with milky fluid and can on this account easily be found; trace this vessel to its entrance into the junction of the subclavian and jugular veins in the neck. Note how richly it is supplied with valves, which are shown by the swellings upon it.

16. Feed a rabbit freely on rice or carrots for one or two days, and then kill it four or five hours after a meal. Rapidly cut out the liver and throw it in small pieces into a vessel containing boiling water just acidulated with

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[1] Half a teaspoonful will make a cupful of paste.

[2] The mixture should be kept at such a temperature that the finger can be kept in it without discomfort, that is to say, at about body-temperature.

acetic acid. This process coagulates the proteid present in the liver. Take the pieces of coagulated liver out of the boiling water after they have been immersed for about a minute, and grind them up with some cold water in a mortar. Filter through muslin, and a very opalescent, almost milky fluid will be obtained which is rich in *glycogen* or animal starch. If the liver be left for some time after death before extracting as described above, all the glycogen becomes converted into grape sugar. A similar change can be induced in the glycogen solution by heating it with acids or with saliva or pancreatic extract. If dilute iodine solution be added to the glycogen solution a deep brown or port-wine colour is produced, which disappears on heating and reappears on cooling. The glycogen may be precipitated from solution by the addition of 60 per cent. of alcohol, and so obtained as a wbite amorphous powder.

This experiment shows that the liver stores up excess of carbohydrate in the form of a variety of starch.

17. Obtain some ox-bile from a butcher and perform the chemical tests for bile salts and bile pigments described on pp. 163 and 164.

18. Fit a bottle with a cork through which two glass tubes, bent once at right angles, pass, one tube reaching to the bottom of the bottle, and the other only just passing through the cork. Fill the bottle nearly full of lime-water, and place the cork in position, apply your mouth to the shorter tube, and *suck* so that atmospheric air bubbles through the lime-water; no change takes place in the lime-water unless the process be continued for a very long time. Now apply your mouth to the longer tube, and *blow* air from your lungs through the lime-water. One or two breaths will prove sufficient to give a white precipitate of calcium carbonate in the lime-water; this is produced by the action of the carbon dioxide liberated in the lungs.

19. Breathe against a clear cold mirror; it becomes clouded by the moisture deposited from the air coming from the lungs, which is saturated with water vapour at the temperature of the body, and hence causes a deposit of water upon any cold surface with which it comes in contact.

20. Tie a glass tube, connected by indiarubber tubing to a U-shaped tube containing a coloured fluid, into the trachea of a dead animal. Now cut into the thorax and thus allow the full atmospheric pressure to act upon the lungs; these partially collapse, and the coloured fluid is driven up in the distal limb of the U-tube. This shows that the lungs are held distended by a partial vacuum existing within the thorax, and at the same time points to how, when the volume of the thorax is enlarged during life that of the lungs must also be enlarged on account of the pressure of the atmospheric air from without acting down the trachea, bronchi, and bronchioles.

21. Perform the experiment on reflex activity indicated on p. 239.[1]

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[1] The frog's head should be removed with scissors, leaving the upper end of the spinal cord exposed, and the remainder of the animal should be vertically suspended by means of a bent pin used as a hook from some convenient support.

Two per cent. solution of acetic acid may be employed for the stimulation.

By diluting the acid, find a strength such that the leg is not drawn up out of a beaker containing the acid until 20 to 30 seconds have elapsed. Wash the leg free again from acid by dipping it in water. Now apply a pinch of common salt to the cut end of the spinal cord, and after a pause of a few seconds, again test the time that elapses before the leg is withdrawn from the same acid. It will usually be found that the interval is enormously increased. This experiment illustrates inhibition; that is, it shows that reflexes can be stopped or delayed by controlling impulses coming from the higher centres. For the salt stimulates nerve fibres in the cord which in a normal condition of the animal would be connected with nerve cells in the brain, and originates impulses down these fibres which for a time stop the reflex act due to the irritation of the lower cells by the acid.

22. Test with a blunt-pointed pair of compasses, the various distances apart at which the two points can be appreciated as distinct, over different regions of the skin (see p. 250).

23. Obtain two or three ox's or pig's eyes from a butcher and make dissections of them.

Clear away from the eyeball all adhering fat and muscles, and note the place where the optic nerve enters, and the external appearance of the eyeball. Insert one blade of a pair of scissors through the sclerotic coat about a quarter of an inch behind the corneo-sclerotic junction, and cut completely round parallel to this junction, and about a quarter of an inch behind it,[1] thus dividing the eyeball into an anterior and a posterior part. When the two parts are pulled apart the vitreous humour is exposed, and is seen to be a beautifully clear jelly-like mass. The vitreous humour usually adheres to the front portion, but can easily be detached and examined. After the vitreous humour has been removed examine the front portion from the inner side.[2] Observe the crystalline lens lying in the middle opposite to the pupil and its mode of attachment by the *ciliary* processes all round the margin to the anterior portion of the choroid coat which is seen surrounding it and forming a black internal coating to the eyeball.[3] The lens is enclosed in a capsule, which is very delicate and easily ruptured. Remove the lens by pressing against it with the handle of a scalpel at one side, or by passing a pin round the margin. Hold the lens up to the light and notice how clear and transparent it is; but on looking through it, especially some time after the death of the animal, three radial lines may be seen which meet at angles of 120° at the centre. These three

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[1] It is advantageous to do this in a vessel of water, the parts are then better seen and less injured in the dissection.

[2] It may be removed from the water for this purpose.

[3] Identify these various structures by the aid of the diagram given on p. 267.

lines are due to the structural arrangements of the lens. By breaking up, in a small quantity of water, with needles it may be seen that the lens is made up of an immense number of transparent fibres running from front to back.[1] These fibres are arranged in three equal bundles, and the tri-radiate arrangement described above is due to the junctions of these bundles. Examine the anterior portion again after the removal of the lens. Observe the *iris*, with its central aperture, the *pupil*, for the admission of the light. The pupil is lenticular in shape in the ox's or pig's eye, and not circular as in the human eye. The back surface of the iris is always black, from the continuation of the choroid containing black pigment over it, the front surface is variously coloured in different individuals. Note how the outer margin of the iris is attached all round at the junction of the cornea and sclerotic coat. Rub away with a blunt knife the black pigment of the choroid lying behind the junction of the cornea with the sclerotic, and you will expose a circular ridge, lying all round the junction. This ridge is formed by the fibres of the ciliary muscle. Make a cut forwards at one point with a sharp knife, so as to pass at right angles through the corneo-sclerotic junction. Some of the fibres of the ciliary muscle run circularly parallel to the junction of cornea and sclerotic (circular fibres), another set run at right angles to the junction, and are attached in front at the junction and behind to the choroid coat. It is evident that when the fibres of the ciliary muscle contract, the choroid will be pulled forward, and hence the processes (ciliary processes), which were previously observed attacking the lens all round to the choroid, will be slackened. The lens will, in consequence, not be so much flattened against the vitreous humour by the pull of these processes, and will become more rounded. This happens when we look at a near object.

Examine next the posterior half. Observe the retina lying innermost of the three coats;[2] this coat is usually detached from the choroid except where the optic nerve enters, and is seen floated up by the water in which it is immersed as a yellow-coloured almost transparent film. Outside this is seen the black choroid coat, and outermost of all there is the sclerotic coat.

24. If an eye can be obtained in a fresh enough condition,[3] the following experiment may be made. Cut a circular opening out of the back part of the eye, including the optic nerve, and about one-third of the posterior surface of the eyeball. Take care that the opening is not large enough to allow the vitreous humour to escape. Now apply a piece of greased paper

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[1] These fibres can be better seen in the case of a lens which has been hardened for some days in two per cent. solution of potassium chromate.

[2] In the eye of the ox there is a thin glistening coat, of a green colour, which is termed the *tapetum*, to the inside of the retina. The purpose of this coat is unknown. It is not present in the human eye.

[3] The cornea rapidly loses its transparency after death, and hence the above experiment is only successful with a fresh eye.

against the opening and turn the eyeball so that light from a window enters it in front. An image of the window will be formed upon the paper behind.

25. The shape of the blind spot may be *roughly* mapped out by the following method. Make an ink spot upon a piece of white paper, close the left eye, and place the right eye vertically opposite the ink spot and about ten inches distant from it. Move the point of a pencil or pen to the *right*, away from the ink spot, keeping the eye always direct upon the ink spot, and not upon the pen point, until the point just ceases to be visible, and mark this spot; continue moving the pen point still further to the right until it again becomes visible, and mark this point also. This gives the horizontal diameter of the blind spot, and the colour may be marked in by moving the pen point up and down above and below this line at intermediate points, and marking in each case the spot at which it is just visible.

26. Try Mayer's experiment, described on p. 274.

TEST QUESTIONS[1]

1. Describe the life-history of the simplest animal organism.

2. State the similarity which exists between the simplest type of living animal and the more complex types.

3. Define the terms "tissue," "organ," and "gland."

4. Describe a typical vertebra, and state in general terms how this structure is modified in various parts of the vertebral column.

5. Describe the articulation of the lower jaw with the skull, and the movements which take place at this joint.

6. Describe the bony framework of the thorax, and the manner in which the volume of the thorax is altered during respiration.

7. State the bones and joints which correspond to one another in the upper and lower limbs.

8. Give a classification of joints, stating the nature of the movement in each, and illustrating by examples.

9. Name the different classes of muscular tissue, state where each kind is to be found, its microscopic appearance, and in general terms its use in the body.

10. How is the erect position of the body maintained?

11. Enumerate the viscera found in the thorax and in the abdomen respectively, and state their position in these cavities.

12. Describe the course of the aorta, and name the principal branches which it gives off.

13. Beginning at the aorta, describe the patb of a blood corpuscle which makes a complete circuit. What is the longest, and what the shortest, path which such a corpuscle could take?

14. State in general terms the purposes served in the body by the circulation of the blood.

15. Describe the walls of the blood-vessels in the cases of arteries, capillaries, and veins, pointing out similarities and differences.

16. What is meant by the "heart sounds"? and how are these caused?

17. Why are the auricles thin-walled and the ventricles thick-walled? and why is the wall of the left ventricle thicker than that of the right ventricle?

18. Where in the circuit does the greatest fall in blood-pressure take place? and what is the cause of this rapid fall?

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[1] These questions are intended to point out important points, which should be specially studied and understood; they should not be attempted until the book has been once carefully read over.

19. What is the cause and the nature of the pulse in the arteries? and why does the blood-flow become uniform in the veins?

20. What determines the relative velocity of the blood-flow in arteries, capillaries, and veins respectively, and what the local velocity in any particular area?

21. Describe the venous valves, and state what use they serve. Which veins have no valves?

22. How would you identify the different chambers in an excised heart? What cuts would you make in it in order to expose the interior of each chamber? What differences are found in the two sides?

23. Describe the tri-cuspid valve. What are the uses of the *chordæ tendinæ* and musculi papillares?

24. Describe the corpuscles found in the blood, and state their functions.

25. What are the names given to the fluid part of the blood before and after clotting respectively? What substances are dissolved in this fluid part of the blood?

26. Enumerate the conditions which respectively hasten and retard coagulation of the blood.

27. State the part which plants play in preparing the food of animals.

28. Into what classes or groups can the substances present in food be divided, and what are the characteristics of each class? Give examples.

29. Give the position of the salivary glands. What is the action of saliva on food?

30. What is meant by the term "*enzyme*"? Enumerate the digestive enzymes, stating in which digestive secretion each is found, and discuss briefly their action on food.

31. State the general characteristics of enzymic action.

32. Describe the two types of gastric gland, and state what constituents of the gastric juice are probably secreted by each type.

33. Enumerate and briefly describe the coats of the wall of the small intestine.

34. Describe a *villus* of the small intestine. What use is served by the villi?

35. Describe, first, the naked-eye appearance of the liver; secondly, its minute structure; and thirdly, the nature and arrangement of its blood-supply.

36. Describe the physical properties of bile; enumerate its chief chemical constituents, and state very briefly the properties of each of these.

37. How have the bile pigments been shown to be related to hæmoglobin? What information does this give as to their source in the body? What is their ultimate fate?

38. What uses do the bile salts serve in the body? What is meant by the term "*circulation of the bile*"?

39. What is meant by the "glycogenic function" of the liver? State the evidence that the liver can also act as a temporary storehouse for other food-stuffs than carbohydrates.

40. What are the meanings of the terms "metabolism," "katabolism," and "anabolism"?

41. Where is fat chiefly stored in the body? Describe the modifications which the cells undergo as they become charged with fat.

42. To what extent can the various kinds of food-stuff replace one another, and be converted into one another in the metabolic processes?

43. Describe concisely the structure of the respiratory apparatus.

44. Describe the changes which (*a*) the air and (*b*) the blood undergo in the lungs in the process of respiration. How may some of these changes be demonstrated?

45. In what manner is the oxygen held in the blood? What circumstances determine the amount of oxygen so held?

46. Why does the blood lose oxygen and take up carbon dioxide in passing through the capillaries of the tissues? Describe the manner of the exchange, as far as is known, between the tissue cells and the blood.

47. What is *asphyxia?* Enumerate some of the ways in which it may be caused.

48. How is the temperature of the body maintained constant?

49. State the channels by which the waste of the body is removed, and mention the chief waste products removed by each.

50. Describe the minute structure of the skin. Briefly describe the structure of a nail, of a hair follicle, and of a sweat gland.

51. Name the parts of the urinary system, and state their relationship to one another.

52. Describe the naked-eye appearance of a kidney as seen in longitudinal section.

53. Describe the course of a uriniferous tubule, and the structure of the cells lining it at various parts.

54. Describe the arrangement of the blood-supply of the kidney.

55. State what you know as to the manner in which the urine is secreted in the kidney.

56. What evidence have we that urea is formed in the liver and not in the kidney? From what substances is urea probably formed in the liver? (See p. 165.)

57. What is the chemical formula of urea, and what is its nature as a chemical compound? What gives this substance its chief importance to the physiologist?

58. Enumerate the other important constituents of normal urine.

59. Under what conditions do abnormal constituents appear in the urine, and what does their presence under such conditions teach us as to the function of the kidneys?

60. State in general terms the work performed in the body by the nervous system.

61. Enumerate the parts of the central nervous system, and very briefly describe each part.

62. Why is it that when one side of the brain is injured, effects are produced upon the opposite side of the body?

63. Enumerate the cranial nerves, and very briefly state the use of each pair.

64. Describe the sympathetic nervous system, and state in general terms what is the nature of its action in the body.

65. Describe a medullated nerve fibre.

66. Describe a simple reflex act.

67. What is meant by the term "co-ordination"?

68. Describe the condition of an animal, such as a frog, from which the cerebral hemispheres have been removed.

69. State concisely the functions of the different parts of the brain and cord.

70. What is the chief difference between the so-called common and special sensations?

71. What is meant by the "muscular sense"? By what nerve endings is it probably called into action?

72. What is the law of "specific sensation"?

73. What is the Weber-Fechner law?

74. State the various injuries to the visual apparatus by which blindness may be occasioned.

75. What evidence is there that there are nerve endings in the skin which are connected with different kinds of sensation?

76. How is the delicacy of touch estimated in different areas of the skin?

77. Describe the bistological appearance of the end organs of taste and of smell.

78. Name the four taste sensations which are usually referred to as primitive. How are these modified so as to give rise to the many flavours which we experience?

79. Describe the structure of the middle ear, and the movements of the auditory ossicles.

80. Describe the structure of the cocblea.

81. Enumerate the changes which take place between the arrival of a sound wave at the *membrana tympani* and the stimulation of the nerve endings in the *organ of Corti.*

82. From what defects in the auditory apparatus may deafness arise?

83. Describe the semicircular canals, and state what is their function.

84. Draw a diagram of a section, from front to back, of the eyeball and mark in the names of the various parts.

85. What is the iris? Why does the pupil vary in size, and how are the changes in size produced?

86. What changes take place in the eye when the attention is directed from a distant to a near object, and how are these changes brought about?

87. Which layer of the retina is sensitive to light, and how has this been shown?

88. What is the "blind spot," and how is its existence demonstrated?

89. What is an "after-image"?

90. What is meant by *simultaneous*, and what by *successive* contrast? Describe an experiment to show the effect of simultaneous contrast.

INDEX

THE END.

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